NASA Contractor Report 181975

PLAN, FORMULATE, AND DISCUSS A NASTRAN FINITE ELEMENT MODEL OF THE UH-60A HELICOPTER AIRFRAME

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Hampton, Virginia 23665-5225

FOREWORD

Sikorsky Aircraft has been conducting a study of finite element modeling of helicopter airframes to improve the prediction of vibration levels. This work is being performed under U.S. Government Contract NAS1–17499. The contract is monitored by the NASA Langley Research Center, Structures Directorate.

This report summarizes the development, documentation, and initial validation of a finite element model of the UH–60A BLACK HAWK Helicopter. The UH–60A finite element model will be used as the basis for evaluating current techniques for predicting helicopter vibrations. Key NASA and Sikorsky Aircraft personnel are listed below.

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TABLE OF CONTENTS

SECTION 1.0
INTRODUCTION

2.

INTRODUCTION

The NASA Langley Research Center is sponsoring a rotorcraft structural dynamics program with the overall objective to establish in the United States a superior capability to utilize finite element analysis models for calculations to support industrial design of helicopter airframe structures. Viewed as a whole, the program is planned to include efforts by NASA, Universities, and the U.S. Helicopter Industry. In the initial phase of the program, teams from the major U.S. manufacturers of helicopter airframes will apply extant finite element analysis methods to calculate static internal loads and vibrations of helicopter airframes of both metal and composite construction, conduct laboratory measurements of the structural behavior of these airframes, and perform correlations between analysis and measurements to build up a basis upon which to evaluate the results of the applications. To maintain the necessary scientific observation and control, emphasis throughout these activities will be on advance planning, documentation of methods and procedures, and a thorough discussion of results and experiences, all with industry–wide critique to allow maximum technology transfer between companies. The finite element models formed in this phase will then serve as the basis for the development, application and evaluation of both improved modeling techniques and advanced analytical and computational techniques, all aimed at strengthening and enhancing the technology base which supports industrial design of helicopter airframe structures. Here again, procedures for mutual critique have been established, and these procedures call for a thorough discussion among the program participants of each method prior to the applications and of the results and experiences after the applications. The aforementioned rotorcraft stuctural dynamics program has been given the acronym DAMVIBS (Design Analysis Method for VIBrationS).

This report describes the work conducted by Sikorsky Aircraft to plan, formulate, and discuss a NASTRAN finite element analysis model of the UH–60A BLACK HAWK helicopter airframe. The NASTRAN finite element analysis model is to be developed for the No. 640 production BLACK HAWK. This specific helicopter is typical of BLACK HAWK's in production at the time of this

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effort, and contains the modifications made to the airframe structure for the External Stores Support System (ESSS). However, the ESSS wings will not be included in the current study.

The NASTRAN finite element model is to be developed in such a manner that it is suitable to predict both static internal loads and vibrations. Furthermore, the procedures used to formulate the model are to be suitable for domestic helicopter design projects.

To this end the specific objectives of this report are to:

1) Identify and describe the functions of the structural and mechanical components of the BLACK HAWK helicopter,

2) Define the guidelines to be used for formulating the NASTRAN model,

3) Document the NASTRAN model for the BLACK HAWK helicopter,

4) Demonstrate that the model produces reasonable and error–free results for static internal loads, normal modes, and forced response analyses.

SECTION 2.0
MODELING PLAN OBJECTIVES

MODELING PLAN OBJECTIVES

The accompanying figure states the modeling plan objectives which are to be met prior to the actual development of the NASTRAN model of the UH–60A BLACK HAWK helicopter. These objectives were specifically designed to ensure that the modeling follow a well defined plan and that the plan be reviewed by members of the U.S. Helicopter Industry.

The first objective is to provide a complete description of the UH–60A to provide a basis for assessing the adequacy of the NASTRAN model. Included in this discussion are a description of the airframe structure, a description of the components of the power and drive train systems and the means by which they are attached to the structure, and a description of the landing gears and their attachment to the structure.

The second objective is to define guidelines for formulating and coding the NASTRAN model. The purpose of these guidelines is to provide a plan for development of the model so that anticipated correlation efforts could identify the modeling techniques used. Included in these guidelines are: the grid point and element numbering conventions, modeling of primary structure, modeling of the components of the power and drive train systems, treatment of landing gears, and the methods used for mass and vibration modeling.

The final objective of the modeling plan was to define test cases for static, normal modes, and forced response analyses to demonstrate the ability of the model to produce reasonable error free results.

MODELING PLAN OBJECTIVES

- Describe UH–60A helicopter
  - Identify primary and secondary structure
  - Power and drive train systems
  - Landing gears
- Define guidelines for formulating and coding the UH–60A NASTRAN model
  - Grid point and element numbering conventions
  - Modeling of primary structure
  - Modeling of the components of the power and drive train systems
  - Treatment of the landing gears
  - Mass modeling
  - Vibration modeling
- Define test cases for demonstrating the accuracy of the model for
  - Statics
  - Normal Modes
  - Forced response

SECTION 3.0
VEHICLE DESCRIPTION

UH–60A VEHICLE DESCRIPTION

The UH–60A is a single rotor helicopter designed for transport of troops and cargo. The aircraft can operate up to 9979 kg. (22000 lbs.) gross weight and cruises at a speed of 74.6 m/sec. (145 kts.). The primary power is provided by two General Electric T700–GE–700 turbine engines located above and on each side of the aft portion of the mid cabin. The rotor system is four–bladed, with a fully articulated elastomeric bearing main rotor head. Directional control is provided by a four–bladed tractor tail rotor mounted on the right–hand side of the tail rotor pylon. Normal main and tail rotor speeds are 258 rpm and 1190 rpm, respectively. The horizontal stabilator is of the moveable type, the angle of attack being controlled by a linear electrical actuator mounted within the pylon and attached to a fitting on the upper surface of the stabilator. The fuel is carried in two large, crashworthy, self–sealing fuel tanks located in the transition section. The landing gear consists of main wheels on each side of the fuselage and a tail wheel. The oleo struts of the three wheels operate as normal air–oil struts in normal landings but are designed to stroke at constant load in crash conditions with high vertical impact velocities. The struts are also used to lower the aircraft until it almost contacts the ground to allow for air transportation in an aircraft with limited ceiling height. Just aft of the tail wheel is a splice in the tailcone which allows manual folding of the tail rotor pylon. The normal crew is a pilot, co–pilot, and crew chief. The UH–60A normally carries 11 troops, but can carry up to 14 with a high density seating arrangement. A cargo hook is provided under the main cabin for transporting cargo using an external sling.

UH-60A VEHICLE DESCRIPTION

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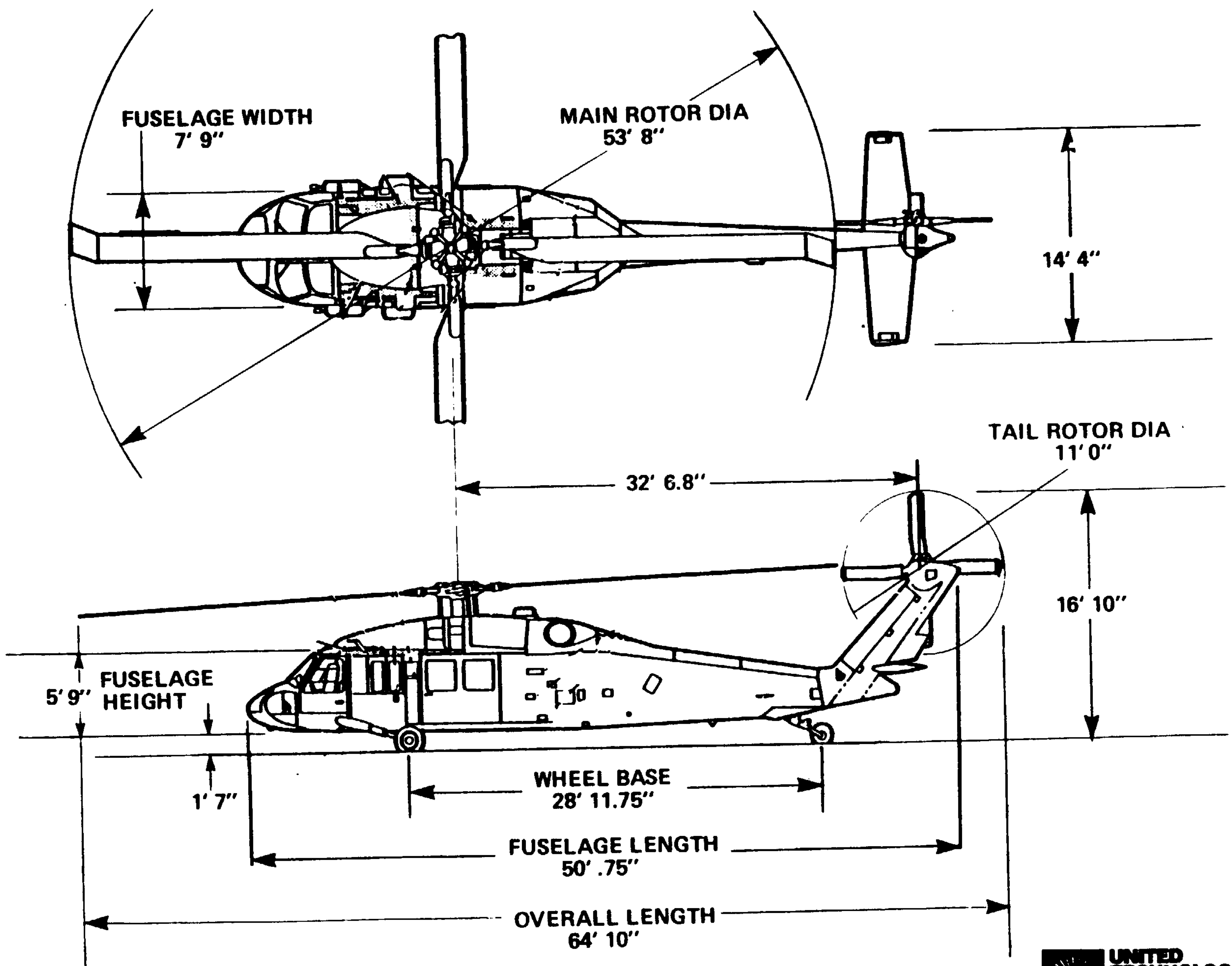
UH-60A OVERALL DIMENSIONS

The accompanying figure shows overall dimensions for the UH-60A aircraft. The overall length and width exclusive of the rotor blades are 15.24 m (50'- 0.75") and 2.36 m (7'- 9"), respectively. The overall length and width including rotors are 19.76 m (64'- 10") and 16.21 m (53'- 2"), respectively. The center to center distance of the main and tail rotor is 9.93 m (32'- 6.8") and the wheel base is 8.83 m (28'- 11.75").

UH-60A OVERALL DIMENSIONS



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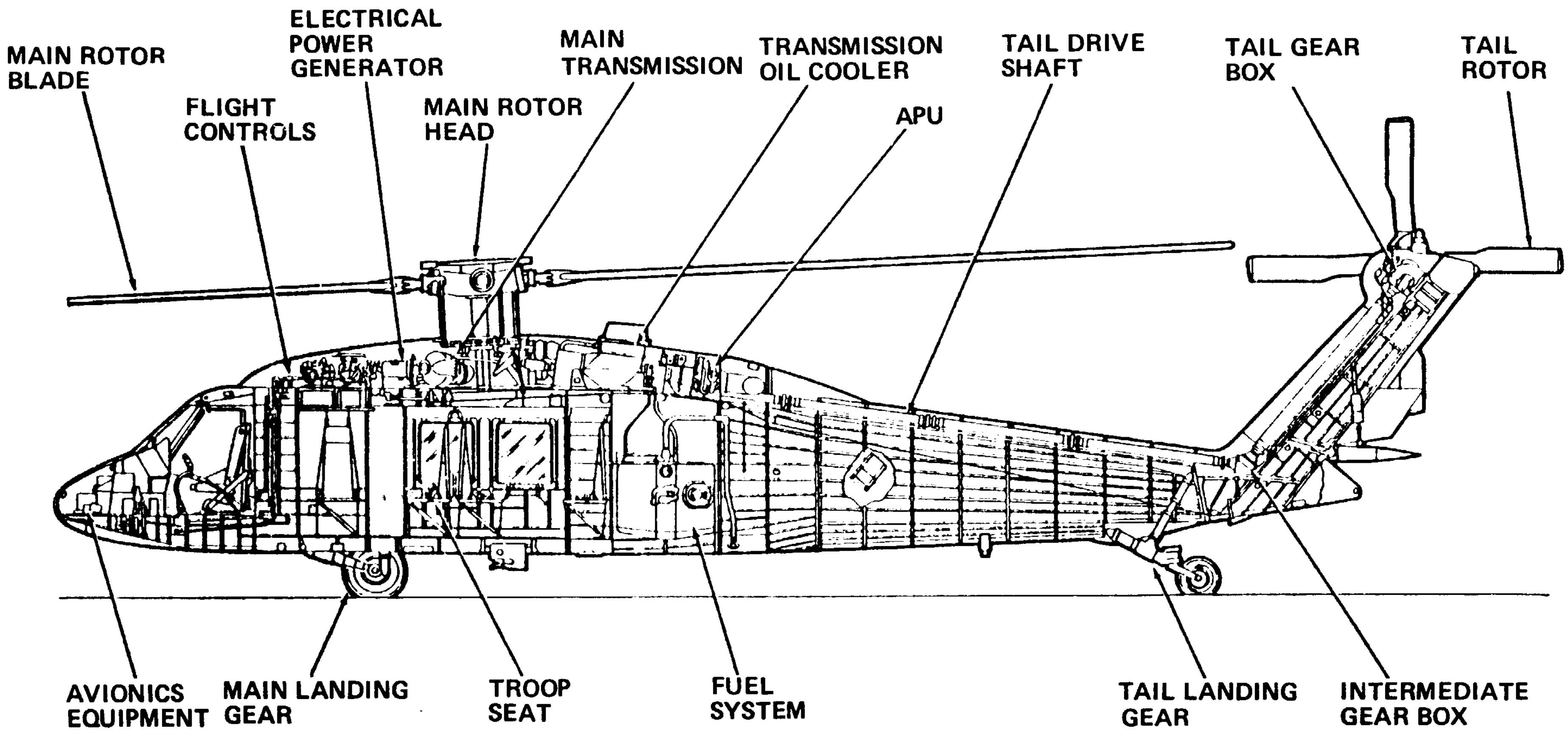
UH–60A GENERAL ARRANGEMENT

The accompanying figure shows the general arrangement of the UH–60A and the locations of the various aircraft components.

UH-60A GENERAL ARRANGEMENT



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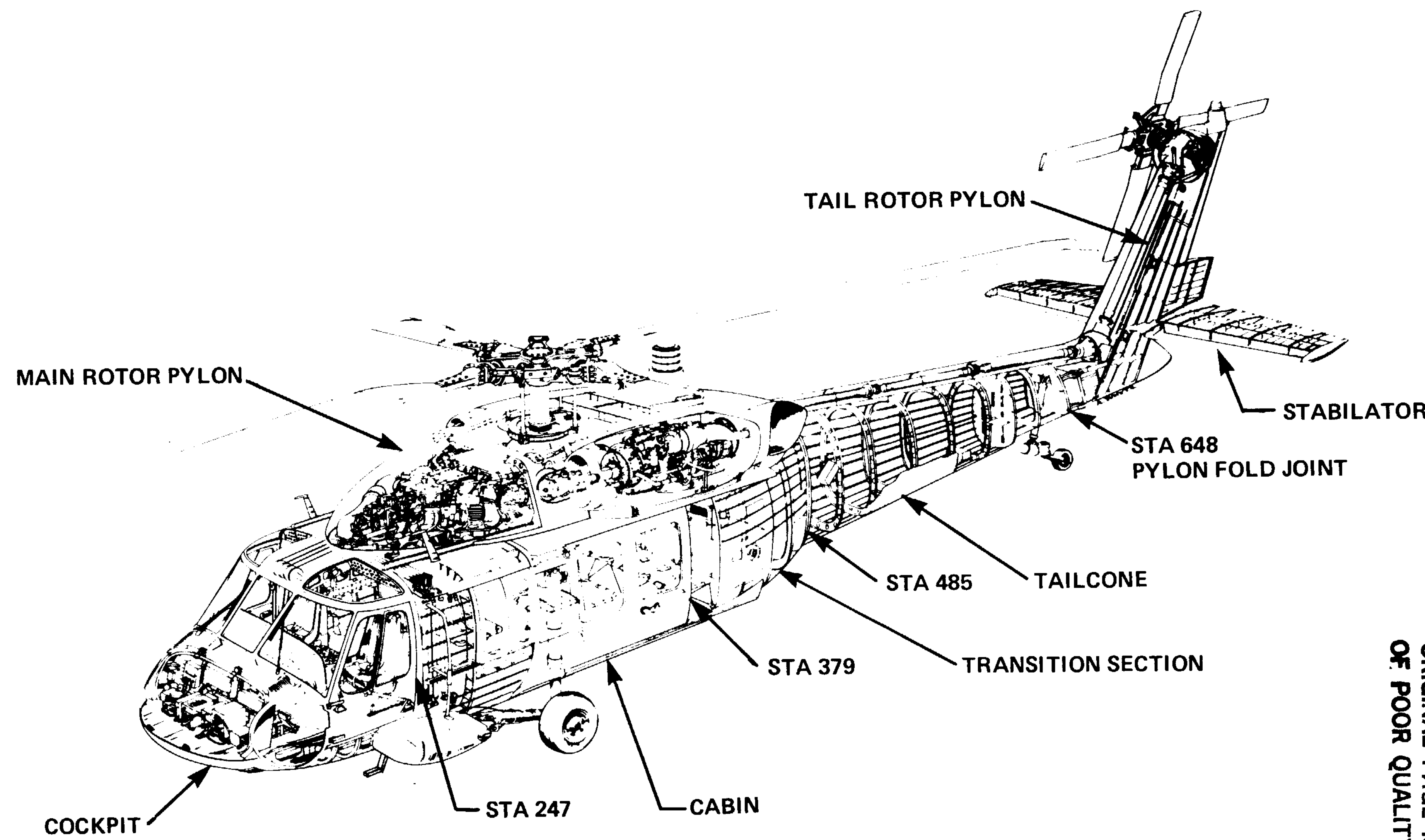
UH-60A PRIMARY FUSELAGE STRUCTURE

The fuselage of the UH-60A helicopter is an aluminum semi-monocoque structure 15.24 m (600.75 in.) long, 2.36 m (93 in.) wide and 1.75 m (69 in.) high consisting of frames, stringers, skins, beams, and bulkheads. Frames and bulkheads are the transverse members of the stucture; stringers and beams are the longitudinal members. The principle material used in the airframe construction is aluminum except in high temperature areas, where titanium is used. Generally, the structure is built up from sheet and extruded stock. In areas with high concentrated loads, such as the transmission support structure, machined aluminum fittings are used.

UH-60A PRIMARY & FUSELAGE STRUCTURE



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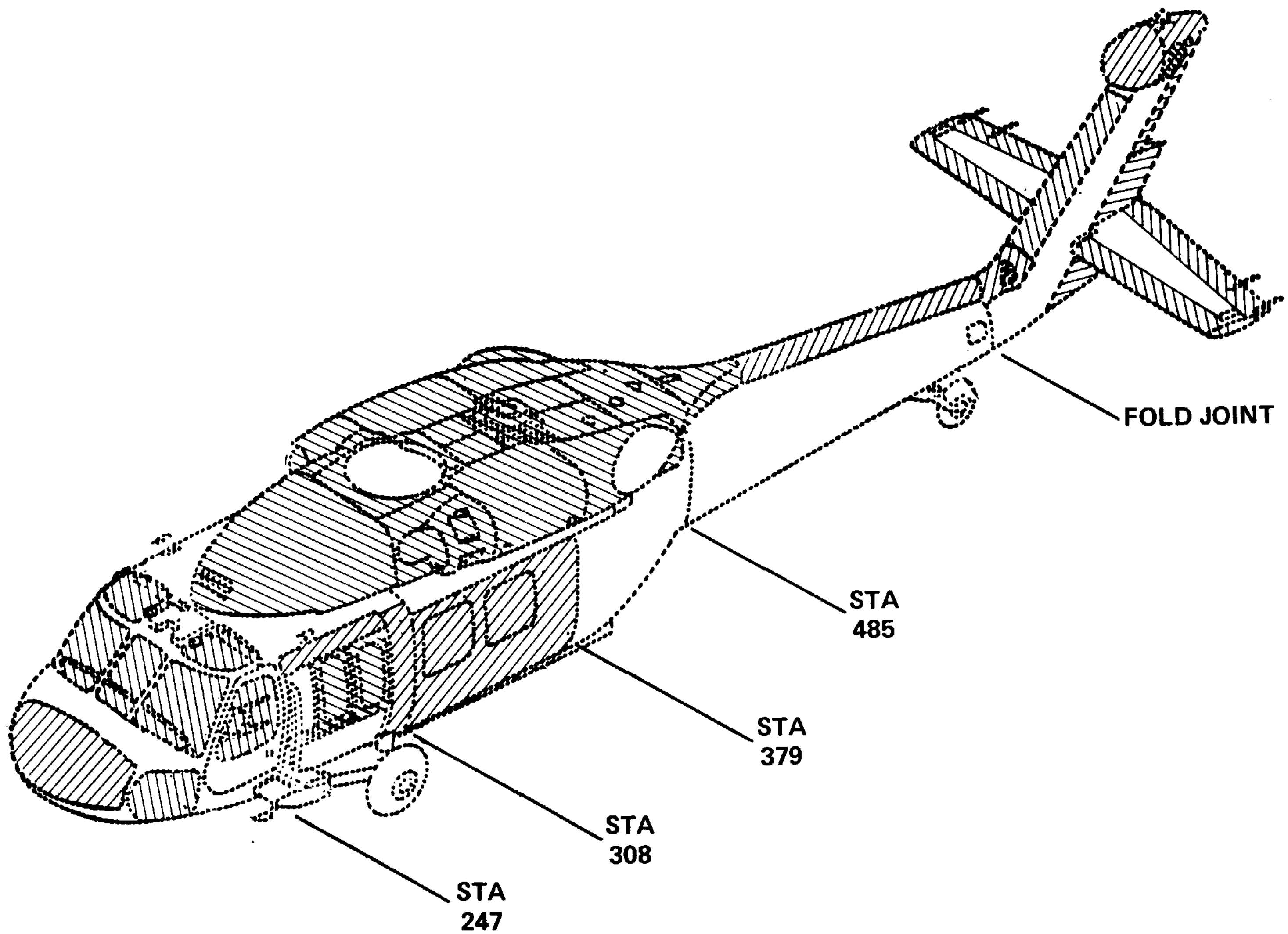
UH-60A SECONDARY STRUCTURE

A number of elements of secondary structure are provided solely for aerodynamic fairing over mechanical components and are not relied on for other structural functions. Generally, fairings are of sandwich construction consisting of aluminum honeycomb cores with laminated fiberglass or Kevlar skins. In some instances laminated fiberglass or Kevlar is used with no core. The windows in the mid cabin and cockpit, except for the windshields in front of the pilot and co-pilot, are stretched plexiglass. The windshields, which have wipers, are of laminated glass construction with an embedded layer of PVB plastic.

The shaded areas in the accompanying figure show the extent of secondary structure in the UH-60A.

UH-60A SECONDARY STRUCTURE



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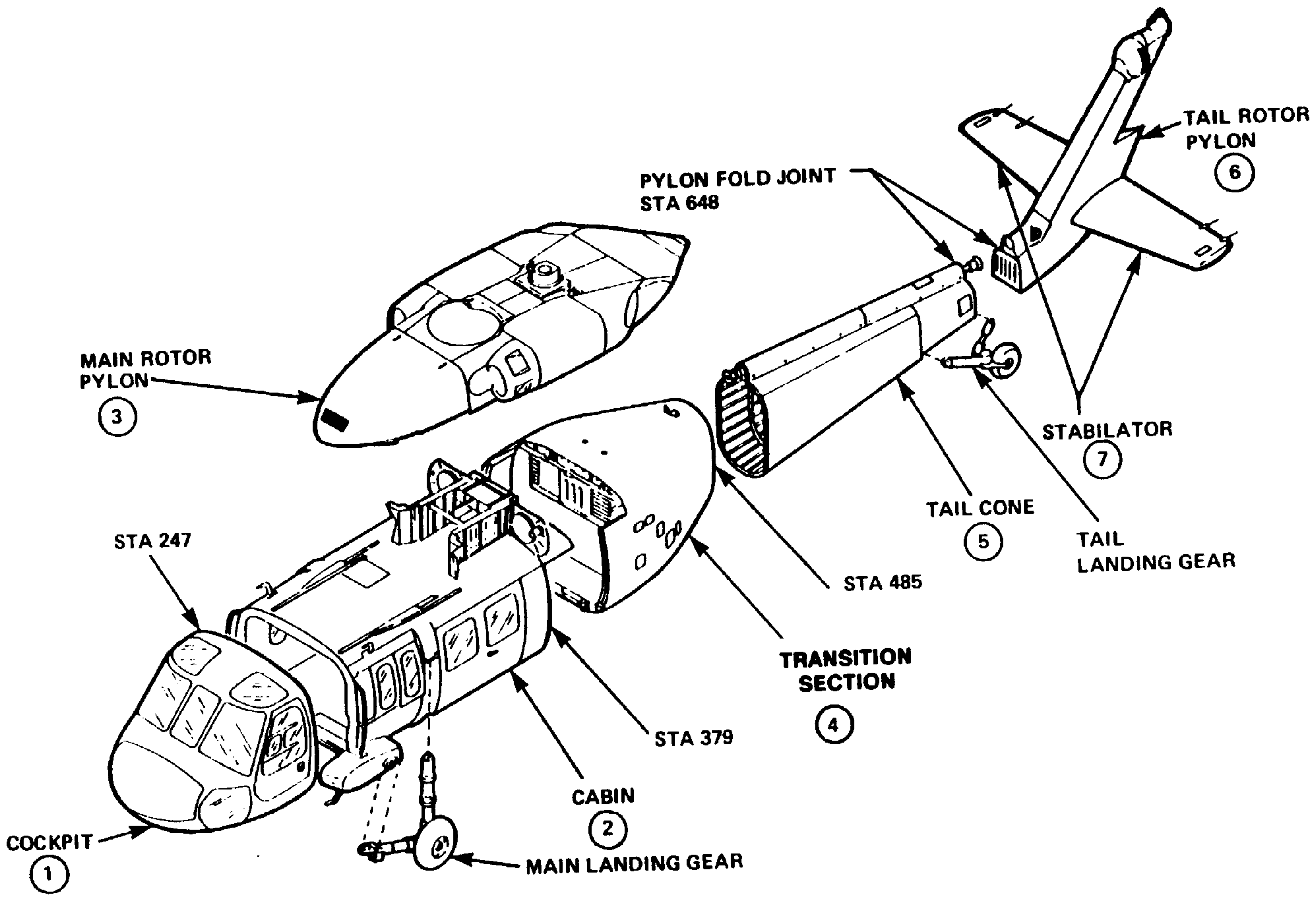
UH-60A AIRFRAME SECTIONS AND MANUFACTURING SPLICES

The following figure shows the basic airframe sections and manufacturing splice locations.

1. Cockpit
2. Cabin
3. Main Rotor Pylon
4. Transition Section
5. Tailcone
6. Tail Rotor Pylon
7. Stabilator

The tail rotor pylon can be manually folded about the fold joint and the stabilator can be removed from the tail rotor pylon. These two features are used for inspections and stowage for air transportation.

UH-60A AIRFRAME SECTIONS AND MANUFACTURING SPLICES



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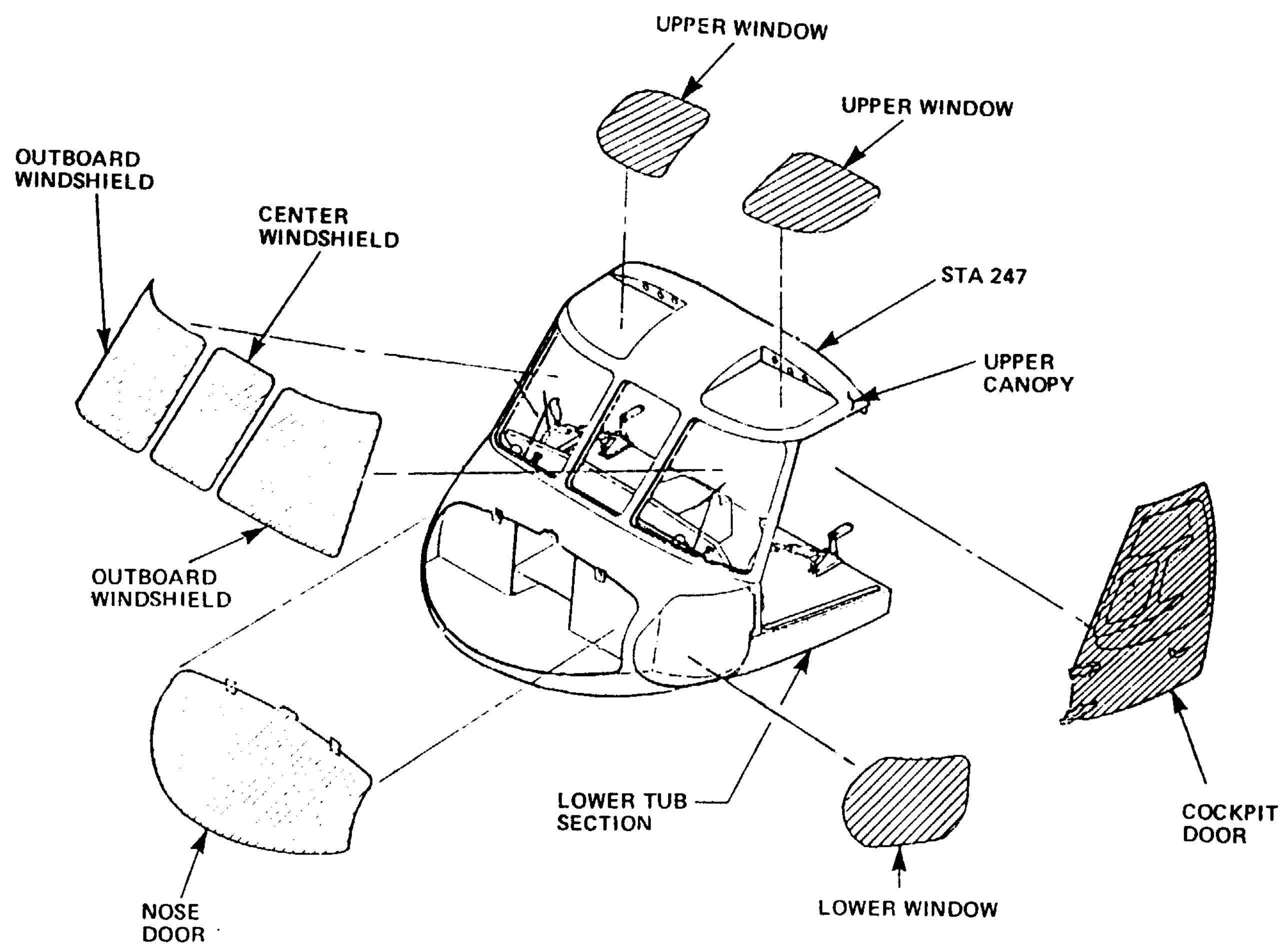
UH–60A COCKPIT

The UH–60A cockpit assembly comprises that portion of the fuselage from the nose at Station 4.15 m (162 in.) to the manufacturing splice at Station 6.27 m (247 in.) It consists of an aluminum lower tub section and a fiberglass upper canopy. The nose door provides access to the avionics compartment located just forward of the instrument panel. The pilot and co–pilot seats, which are armored, are energy absorbing crashworthy seats that are supported by the lower tub structure. The cockpit doors on both sides are jettisonable for rapid exit in emergency situations.

UH-60A COCKPIT



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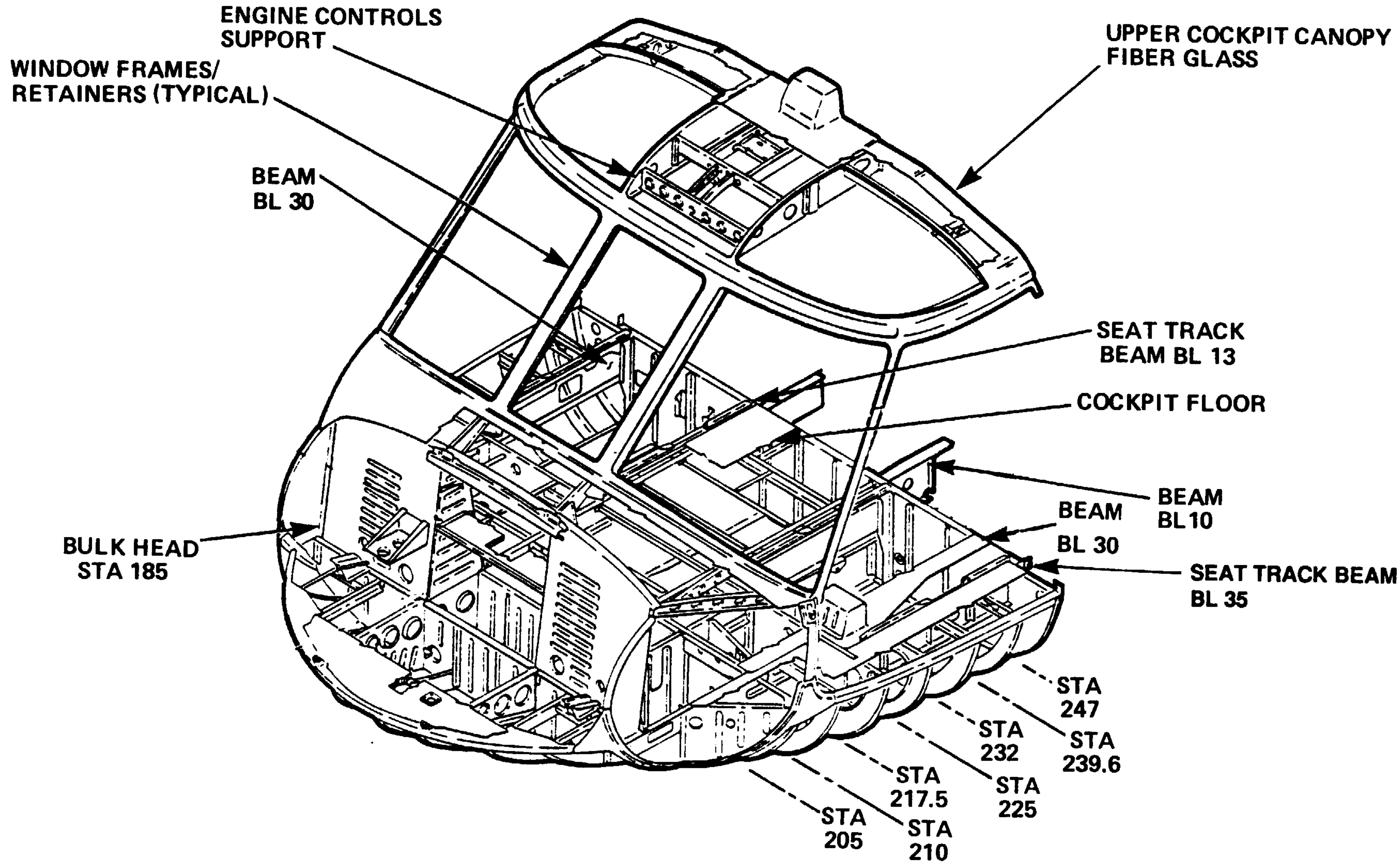
UH-60A COCKPIT
Structural Arrangement

The lower tub section is a box section cantilevered from the fuselage with four major longitudinal beams at BL 0.254 m (10 in.) and BL 0.762 m (30 in.) on both the R.H. and L.H. sides. The box is closed on the bottom by the fuselage skins and on the top by the cockpit floor. The crew seats are mounted on tracks which are supported by beams at BL 0..330 m (13 in.) and BL 0.889 m (35 in.) on each side of the aircraft. These beams span the distance between Station 5.52 m (217.5 in.) and Station 6.27 m (247 in.) which are the major bulkheads in the cockpit. The upper canopy provides support for the overhead windows, windshield, lower windows, and jettisonable doors. The canopy structure is designed by airloads.

UH-60A COCKPIT
Structural Arrangement



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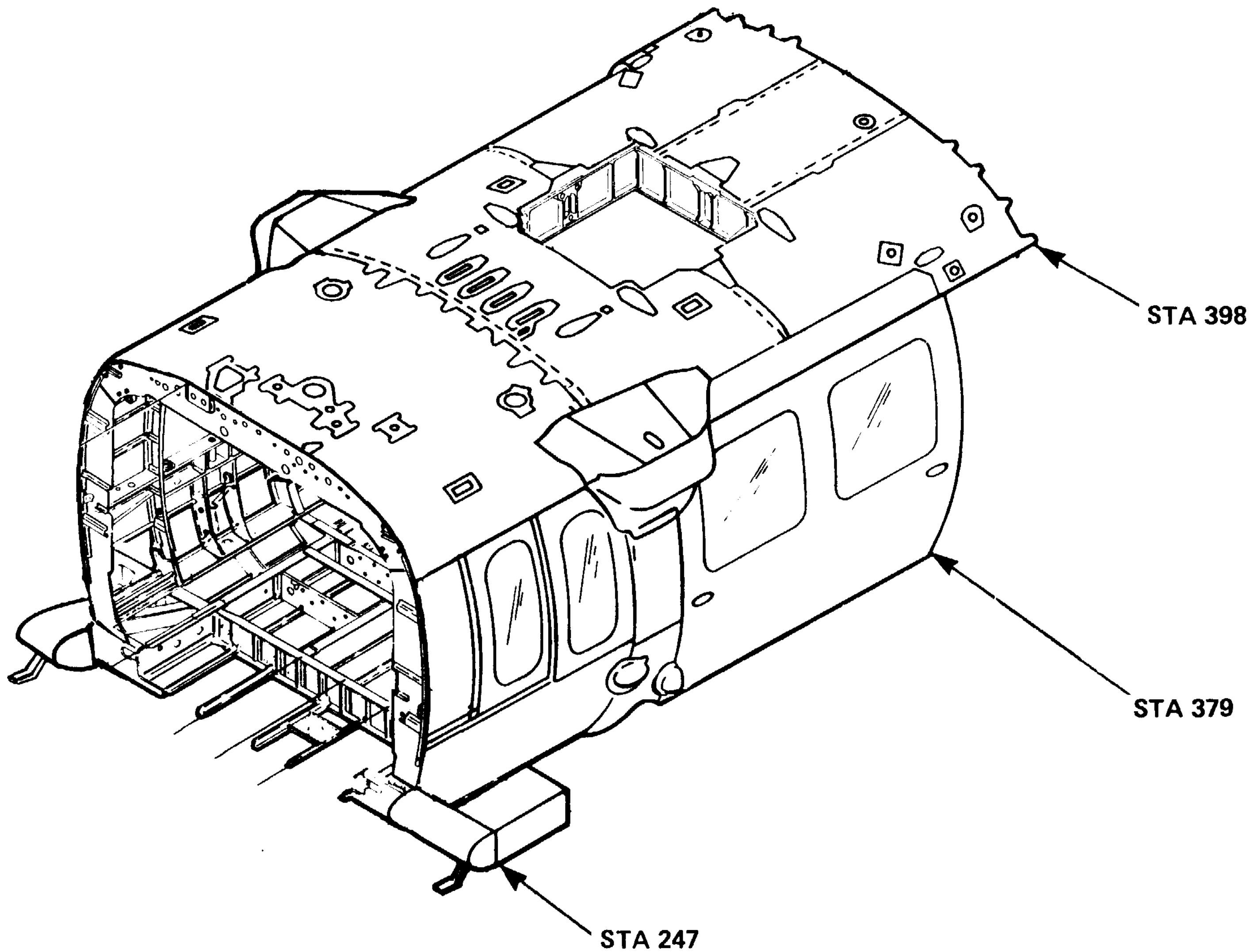
UH-60A CABIN SECTION

The cabin is a constant section that extends from Station 6.27 m (247 in.) to Station 9.63 m (379 in.) in the lower floor section and side and to Station 10.11 m (398 in.) in the upper section. For ease of manufacture, the cabin is manufactured in four sections: the upper deck, L.H. side, R.H. side, and lower tub. The cabin is equipped with twelve crashworthy seats, supported by harnesses attached to the floor and ceiling, to accomodate the crew chief and eleven troops. For rapid loading and unloading of troops or cargo, large aft-sliding doors are provided on both sides of the aircraft between Station 7.82 m (308 in.) and Station 9.63 m (379 in.). Each door has two large jettisonable windows to allow for emergency escape if fuselage deformation prevents normal opening of the door after a crash.

The cabin section provides the structural support for the cockpit and transition sections, main rotor gearbox, engines, and main landing gear.

UH-60A CABIN SECTION



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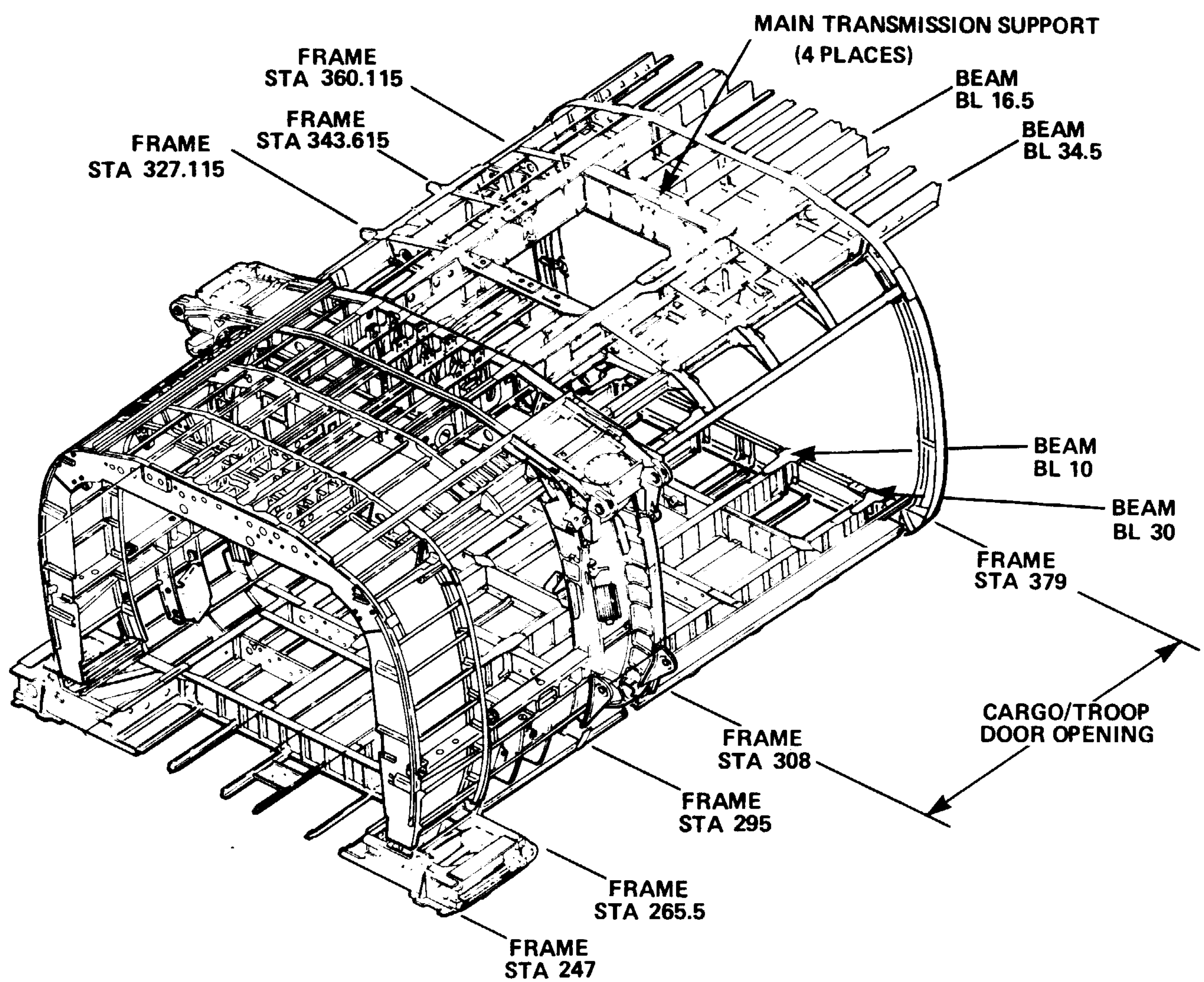
UH-60A CABIN
Structural Arrangement

The cabin is constructed of built-up aluminum sections and machined aluminum fittings in areas where high concentrated loads are introduced. The upper deck, which supports the main transmission, spans the cargo door cut-outs between Stations 7.82 m (308 in.) and 9.63 m (379 in.). It consists primarily of beams at BL 0.42 m (16.5 in.) and BL 0.88 (34.5 in.) that are supported by frames at Stations 7.49 m (295 in.) and 7.82 m (308 in.) at the forward end and Stations 9.63 m (379 in.) and 10.11 m (398 in.) at the aft end. Partial frames are located in the cut-out areas at Stations 8.31 m (327.115 in.), 8.73 m (343.615 in.), and 9.14 m (360.115 in.).

The cabin section also supports the main landing gear. Vertical loads from the landing gear oleo strut are introduced at the upper sides of the primary frames at Stations 7.49 m (295 in.) and 7.82 m (308 in.) and distributed to the fuselage. The landing gear drag beam introduces vertical, side, and drag loads to the stub wing, which is a box section that extends outboard from the frames at Stations 6.27 m (247 in.) and 6.74 m (265.5 in.).

The primary buttline members of the lower tub section are beams at BL 0.254 m (10 in.) and 0.762 m (30 in.) on both sides of the aircraft. They serve to distribute the external cargo hook and floor loads to the supporting frames.

UH-60A CABIN STRUCTURAL ARRANGEMENT



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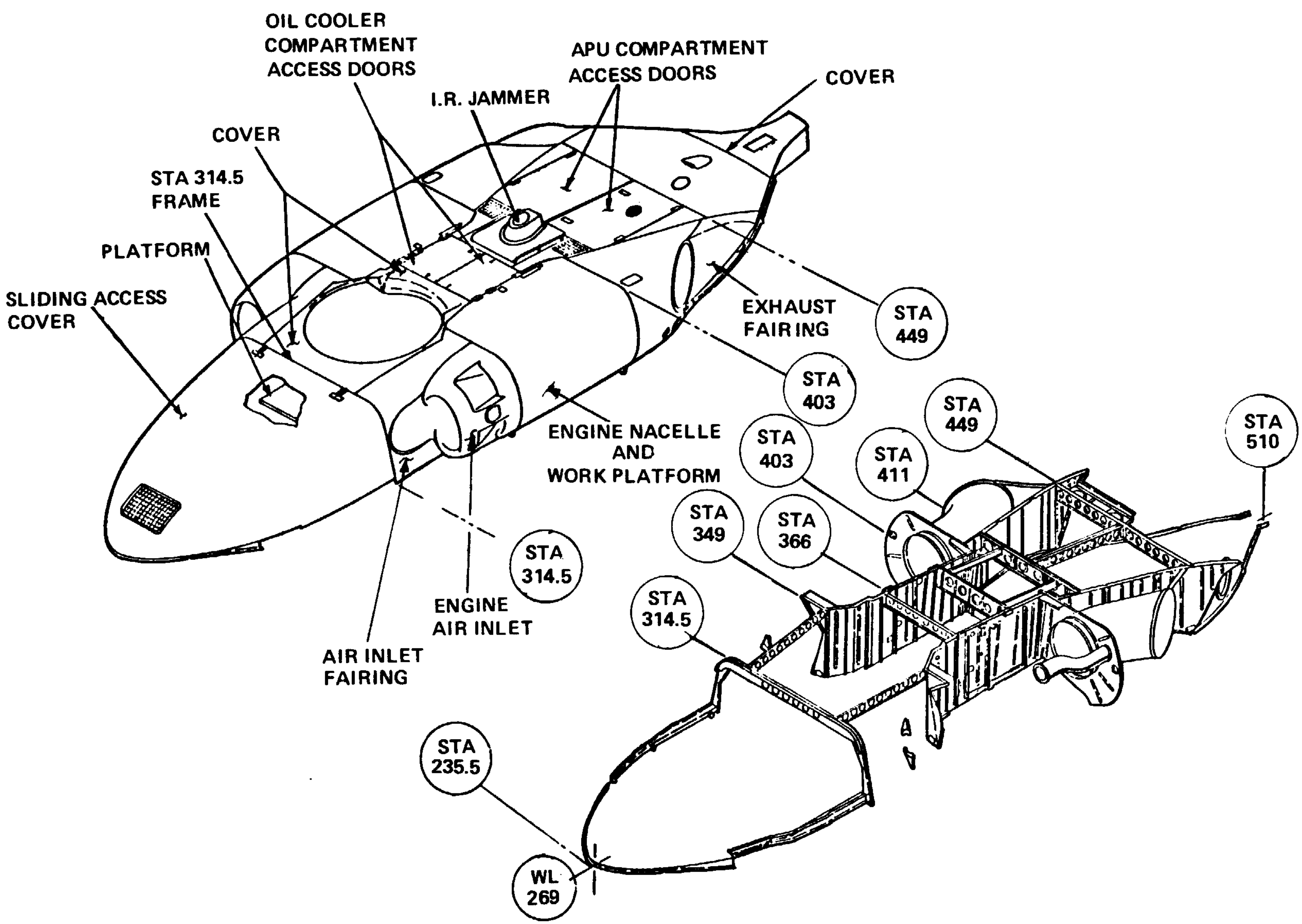
UH-60A MAIN ROTOR PYLON

The UH-60A main rotor pylon is that structure which extends above the top deck, WL 6.83 m (269 in.). Extensive use of sandwich construction provides a rigid light weight fairing, suitable for the type of loading imposed which is mainly aerodynamic pressure loads and maintenance crew loads (work area). Access is provided by a large forward sliding cover (fwd of Station 7.99 m (314.5)), oil cooler compartment doors (Stations 9.30 m (366 in.) to 9.86 m (388 in.)), APU access doors (Stations 10.44 m (411 in.) to 11.40 m (449 in.)), and the engine nacelle that opens to become a work platform. Firewalls and other components subjected to high temperatures are fabricated from built-up titanium sheet stock with combinations of spot welding and riveting.

UH-60A MAIN ROTOR PYLON



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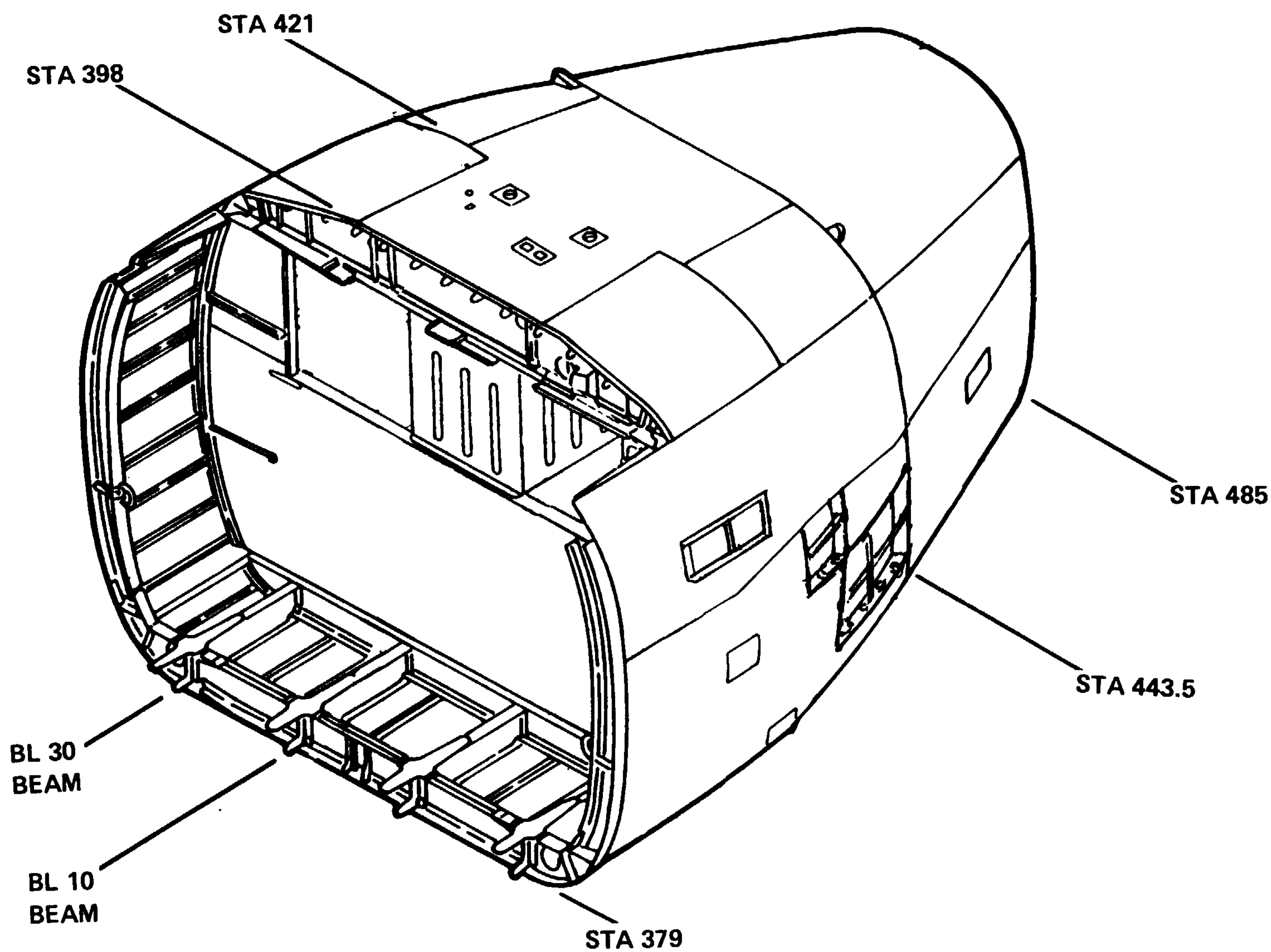
UH-60A TRANSITION SECTION

The transition section extends from Stations 9.63 (379 in.) to 12.32 m (485 in.), and provides the interface structure between the cabin and tailcone sections. The structure is of semi-floating frame construction, that is, the stringers run outside the structural frame cap member with a shear attachment between stringers to the skin (castellations).

The transition section primarily serves to house the two crashworthy self sealing fuel cells which are between the bulkheads at Stations 10.11 m (398 in.) and 11.26 m (443.5 in.). They are symmetrically situated about BL 0.0 and separated by a vertical honeycomb sandwich panel. Four intermediate frames and four longitudinal beams distribute the fuel loads to the fuselage structure.

UH-60A TRANSITION SECTION

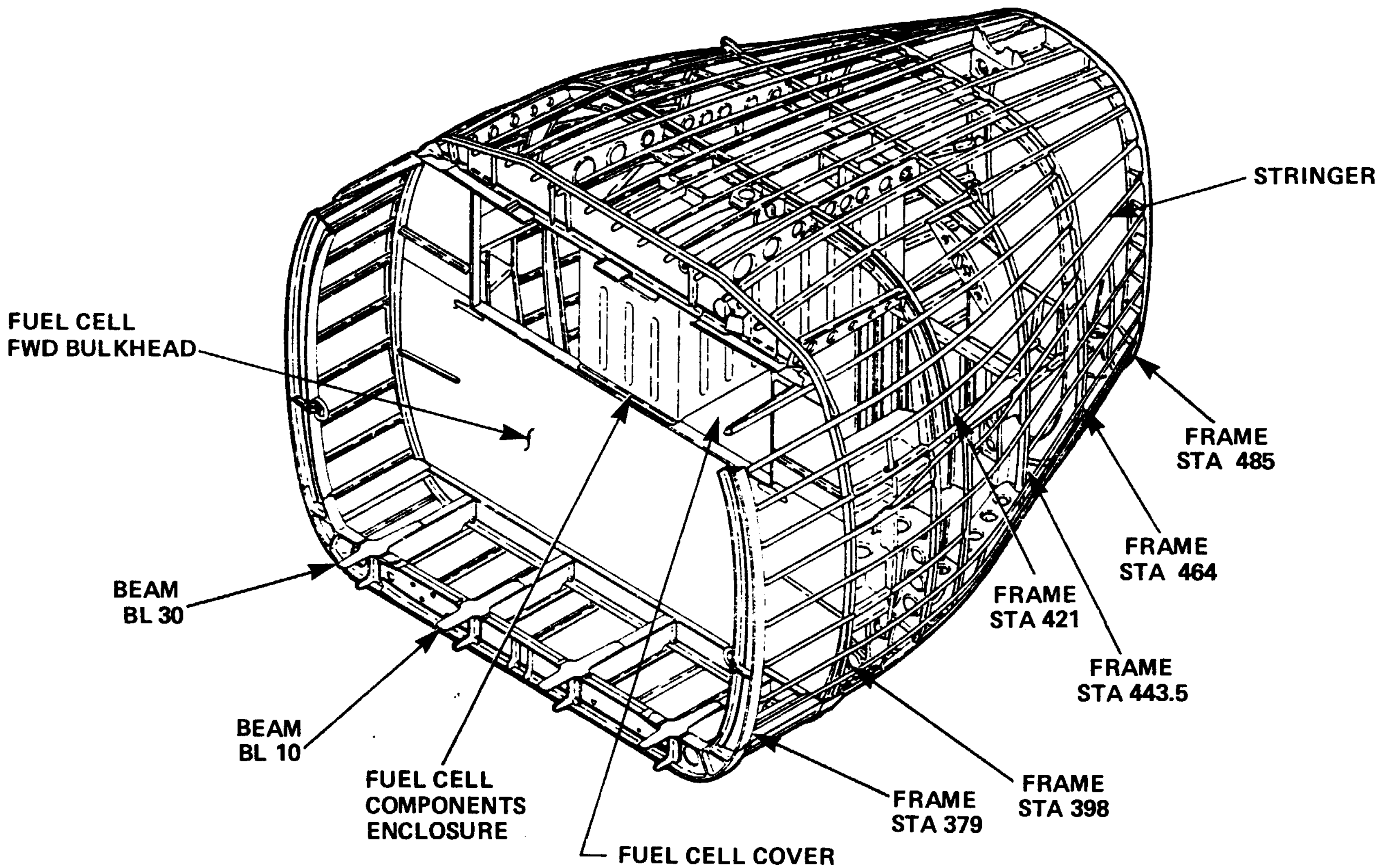


UH-60A TRANSITION SECTION
Structural Arrangement

The fuel cells are supported below WL 6.05 m (238 in.) by the fore and aft bulkheads at Stations 10.11 m (398 in.) and 11.26 m (443.5 in.). The bulkheads have cutouts to provide access to the equipment storage compartments and the fuel system component enclosure. The bulkheads have angle cap sections and are stiffened by 0.05 m (2 in.) deep channel sections running vertically at approximately 0.15 m (6 in.) spacing. The cells are separated at BL 0 by a 0.03 m (1 in.) thick honeycomb panel, and are enclosed at the top by honeycomb panels. The bottom and outboard sides of the cells are supported by a grid work of formed sheet metal frames and by beams at Buttlines 0.25 m (10 in.) and 0.76 (30 in.) on both sides of the aircraft. These beams, which terminate at Station 11.26 m (443.5 in.), are a continuation of those in the main cabin. The stringers in the transition section are spliced to the tailcone at Station 12.32 m (485 in.) via machined bathtub fittings.

UH-60A TRANSITION SECTION

Structural Arrangement



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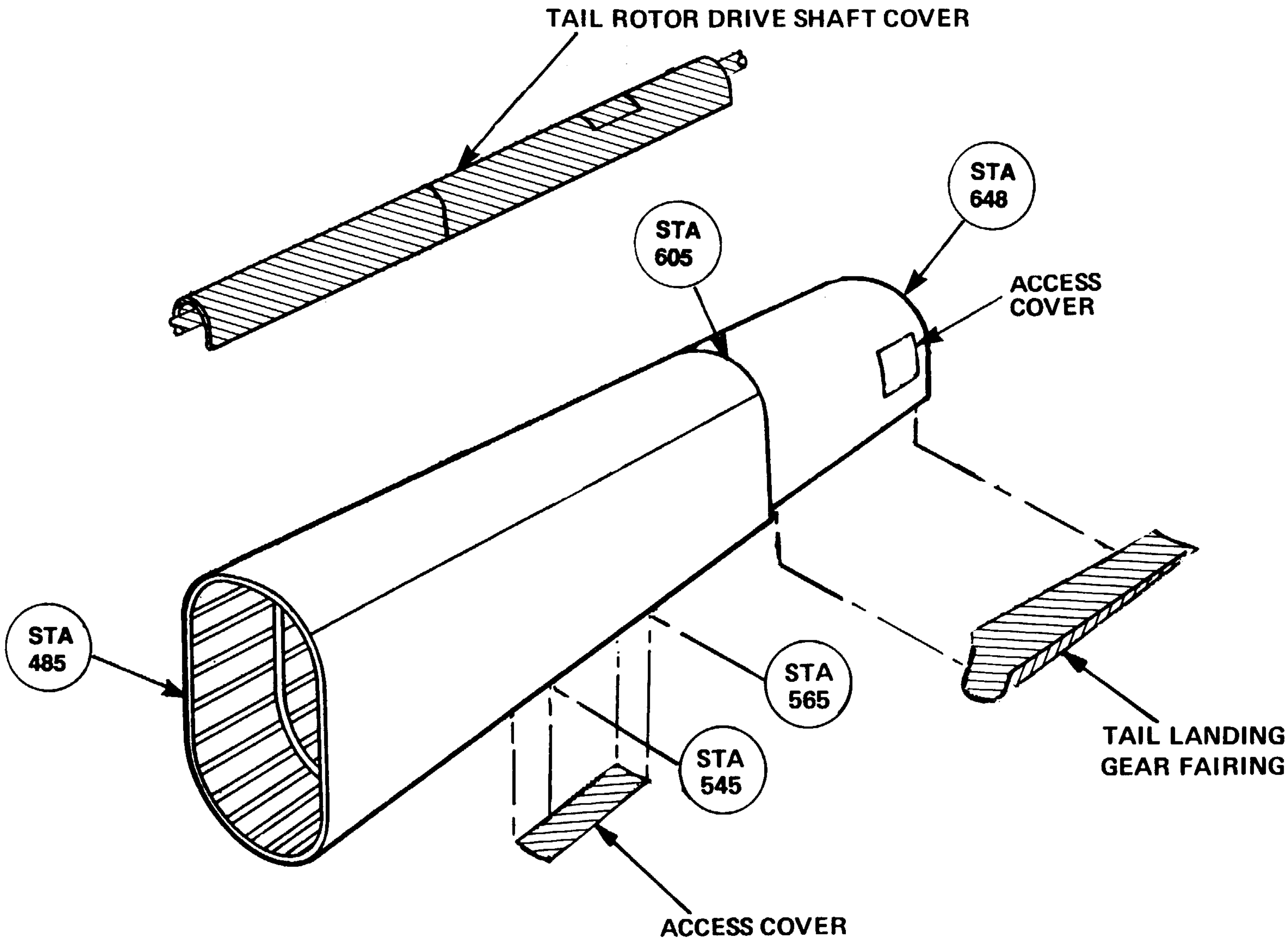
UH-60A TAILCONE

The tailcone extends from the manufacturing splice at Station 12.32 m (485 in.) to the tail rotor pylon fold joint at Station 16.45 (648 in.). The tail rotor drive shaft is located on the top of the tailcone at BL 0 and runs the length of the tailcone outside of the basic contour. The shaft is faired in by a hinged fiberglass cover that provides access to the drive shaft for maintenance. There is also a lower cover between Stations 13.84 m (545 in.) and 14.35 m (565 in,) to allow access to the inside of the tailcone.

The pylon folding is accomplished by removal of four bolts from the Station 16.45 m (648 in.) forward fold bulkhead. A structural cover is provided just forward of the bulkhead to provide access to the bolts.

UH-60A TAILCONE



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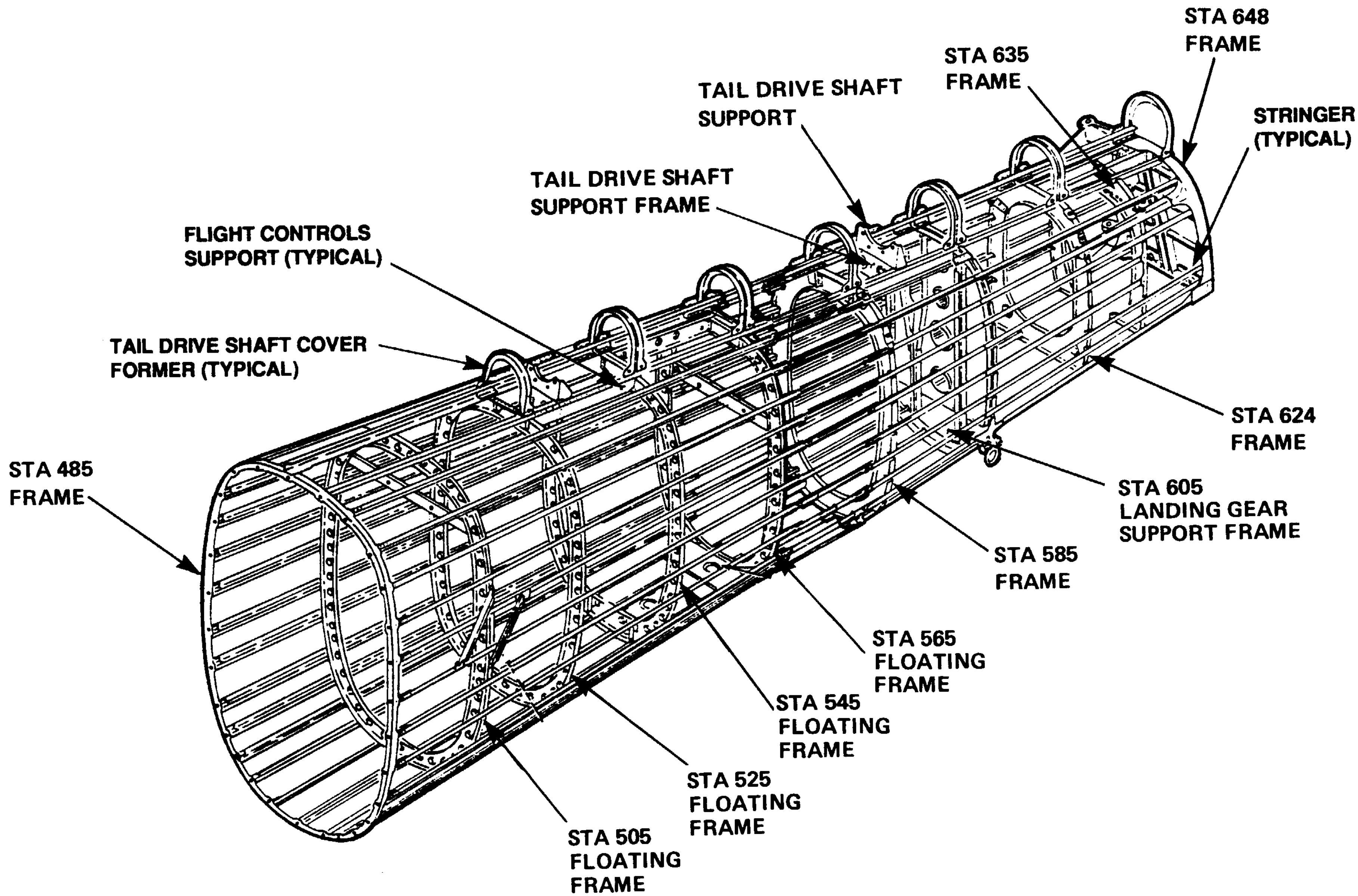
UH-60A TAILCONE
Structural Arrangement

The tailcone is of semi-monocoque floating frame construction, that is, the stringers run on the outside of the frame cap with no skin to frame attachment. The floating frames are at Stations 12.87 m (505 in.), 13.34 m (525 in.), 13.84 m (545 in.), and 14.35 m (565 in.) and are formed sheet metal. The skins are divided into four panels: the top, bottom, right and left hand sides. The formed sheet metal stringers are preassembled to the skins and then attached to the frames on final installation.

The tail landing gear drag beam attaches to the tailcone at Station 15.37 m (605 in.) where the landing gear drag and side loads are introduced. The vertical loads from the tail gear oleo strut are introduced at Station 16.45 m (648 in.). Bulkheads are provided at both stations to distribute the concentrated loads into the tailcone. Also, the Station 16.45 m (648 in.) bulkhead redistributes flight loads from the tail rotor pylon across the fold joint. The joint consists of four tension bolts and eight shear pins.

UH-60A TAILCONE
Structural Arrangement



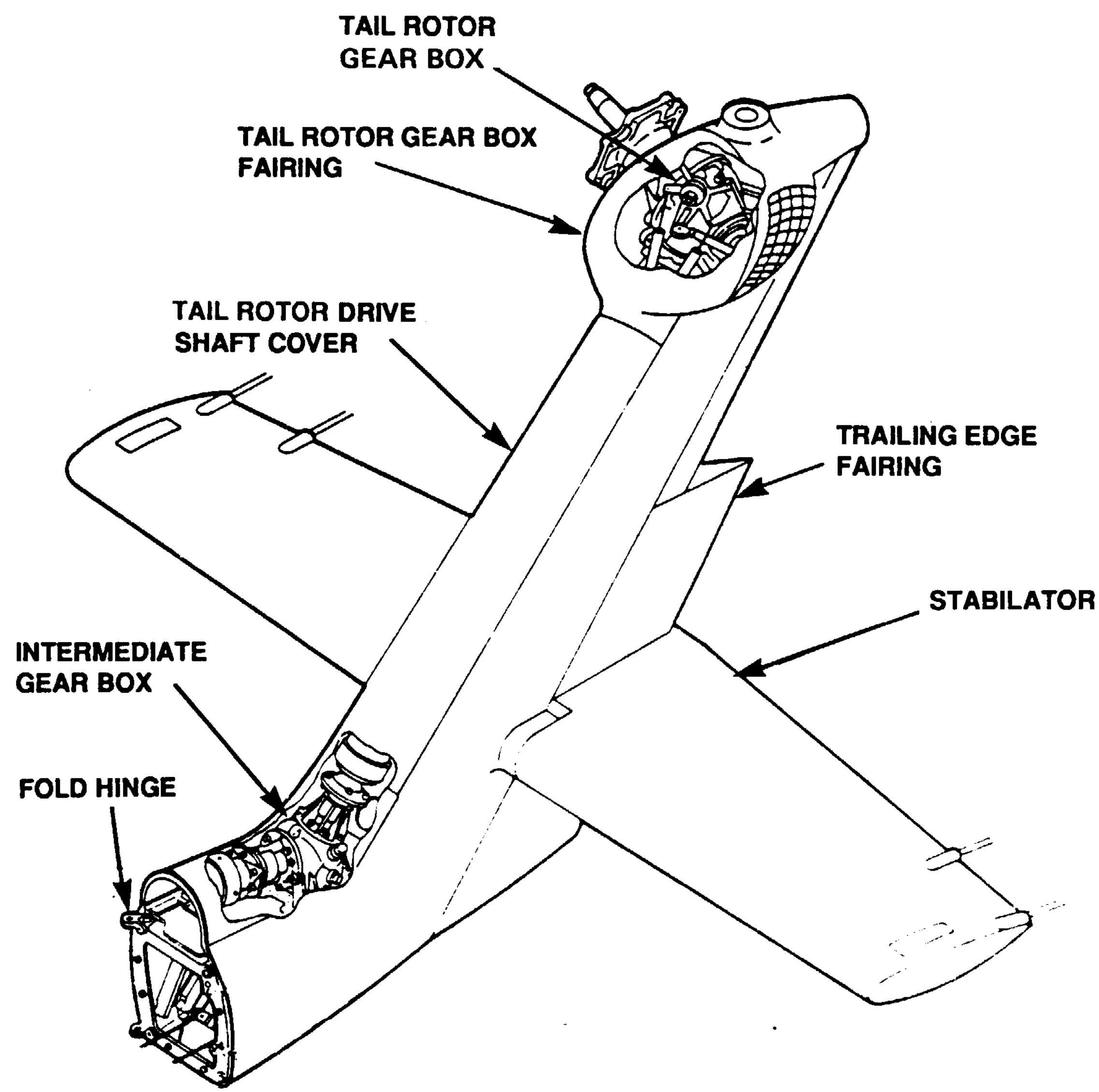
UNITED TECHNOLOGIES SIKORSKY AIRCRAFT

UH-60A TAIL ROTOR PYLON AND STABILATOR INSTALLATIONS

The tail rotor pylon is considered to be all structure aft of the fold hinge bulkhead at Station 16.45 m (648 in.) with the exception of the horizontal stabilator. The tail rotor gearbox is attached to the top leading edge of the pylon. There are two tail rotor drive shaft sections. One extends from the fold hinge bulkhead to the intermediate gearbox, and the other from the intermediate gearbox to the tail rotor gearbox. A hinged fiberglass tail rotor drive shaft cover provides access to the drive shafts and gearboxes. Trailing edge fairings are provided to decrease drag on the pylon.

The horizontal stabilator consists of right and left hand side panels joined to a center box structure which mounts the assembly to the pylon via two sets of fail-safe lugs. Angle of attack change of the stabilator is accomplished by a linear electric actuator mounted within the pylon and attached to a fitting on the upper surface of the stabilator. The stabilator is removable.

UH-60A TAIL ROTOR PYLON AND STABILATOR INSTALLATIONS



UNITED TECHNOLOGIES SIKORSKY AIRCRAFT

UH-60A TAIL ROTOR PYLON
Structural Arrangement

The structure comprising the tail rotor pylon is divided into two parts; the horizontal section which is generally referred to as the lower pylon, and the vertical section which is referred to as the vertical pylon.

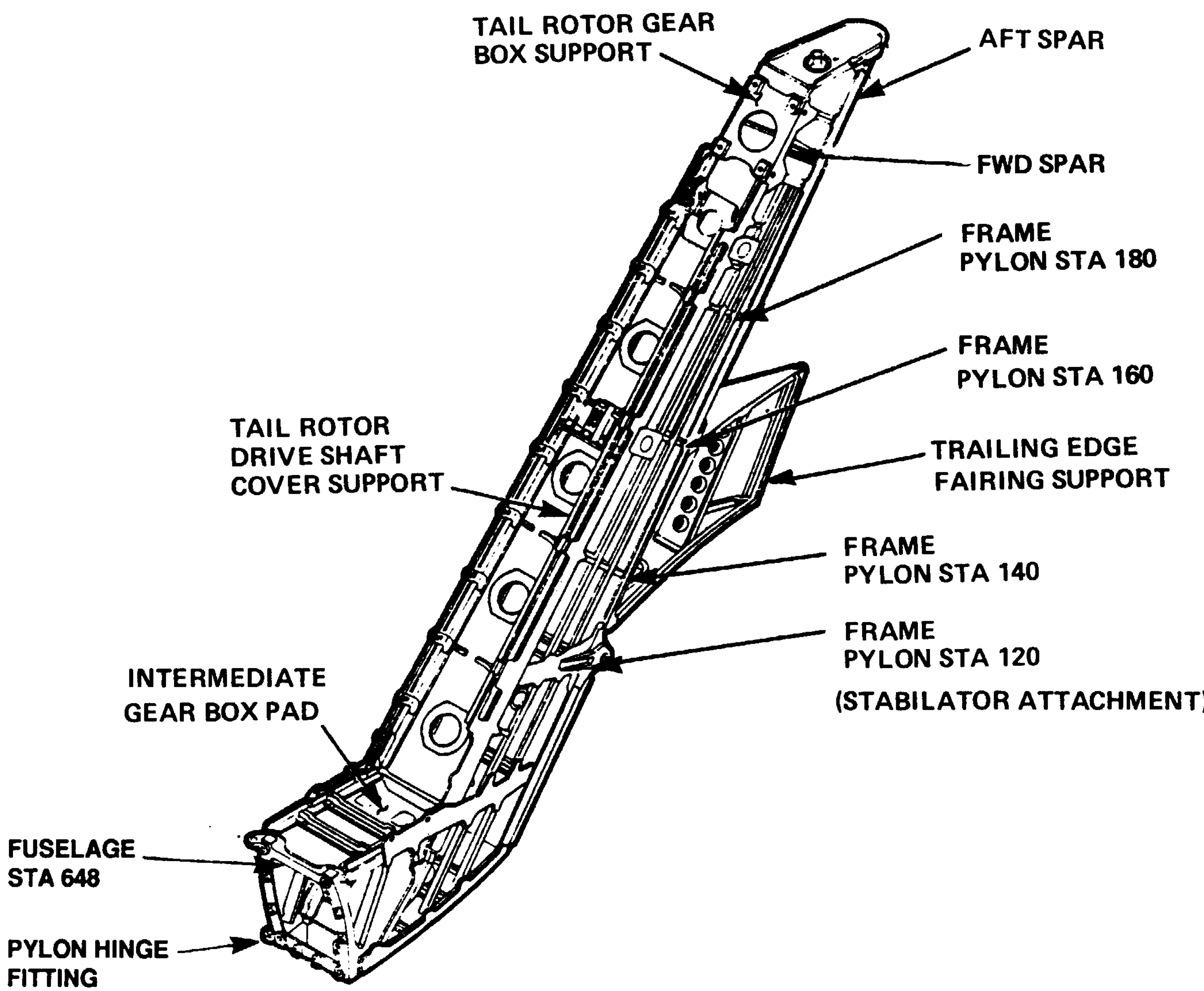
The lower pylon structure, which extends aft from the pylon fold joint at Station 16.45 m (648 in.), is basically a four-sided box structure with corner longerons. The vertical pylon is also a box section consisting of forward and aft spars with side skins and intermediate frames spaced 0.15 m (20 on.) apart. The basic structure of the lower and vertical pylons is built up from aluminum sheet metal stock.

The intermediate gear box mounts to the upper deck of the lower pylon just forward of the splice to the vertical pylon forward spar. The tail rotor gear box mounts to the forward spar of the vertical pylon by means of an aluminum fitting. The fitting splices to the forward spar and to the pylon bulkheads at Pylon Stations 5.08 (200 in.) and 5.33 m (210 in.).

The stabilator is mounted on two lug fittings that also splice the aft spar caps at Pylon Station 3.05 m (120 in.). The bulkhead at Pylon Station 3.05 m (120 in.) distributes the stabilator loads to the pylon.

UH-60A TAIL ROTOR PYLON

Structural Arrangement



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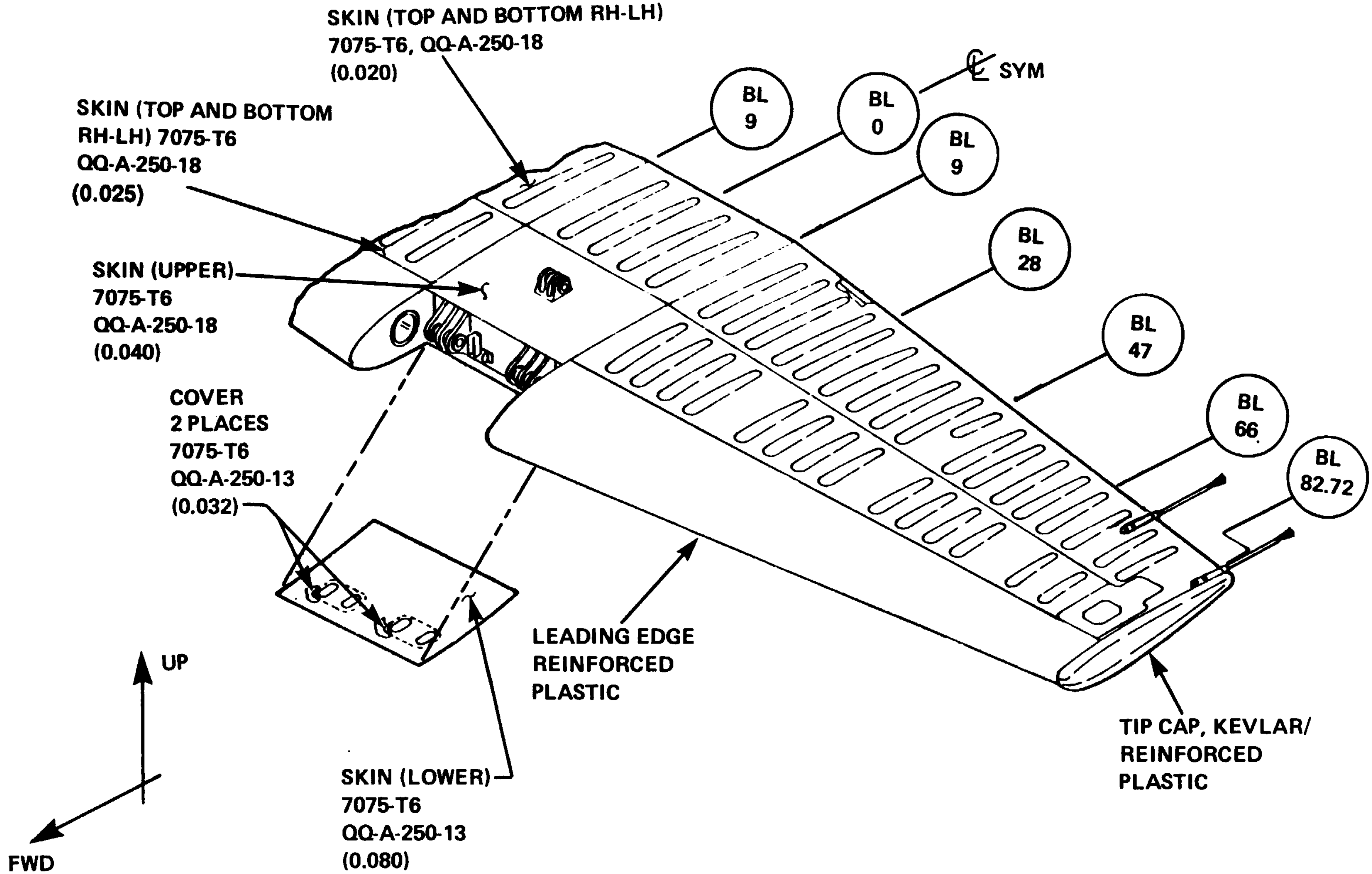
UH-60A STABILATOR

The stabilator consists of a leading edge, center structural box, and trailing edge. The leading edge is of sandwich construction with a honeycomb core and fiberglass skins. The remainder of the stabilator is built up of aluminum sheet metal stock except in areas with high concentrated loads. Fail-safe lugs are provided on the forward spar and BL 0.0 rib to pick-up the pylon pivot points and stabilator actuator, respectively.

UH-60A STABILATOR



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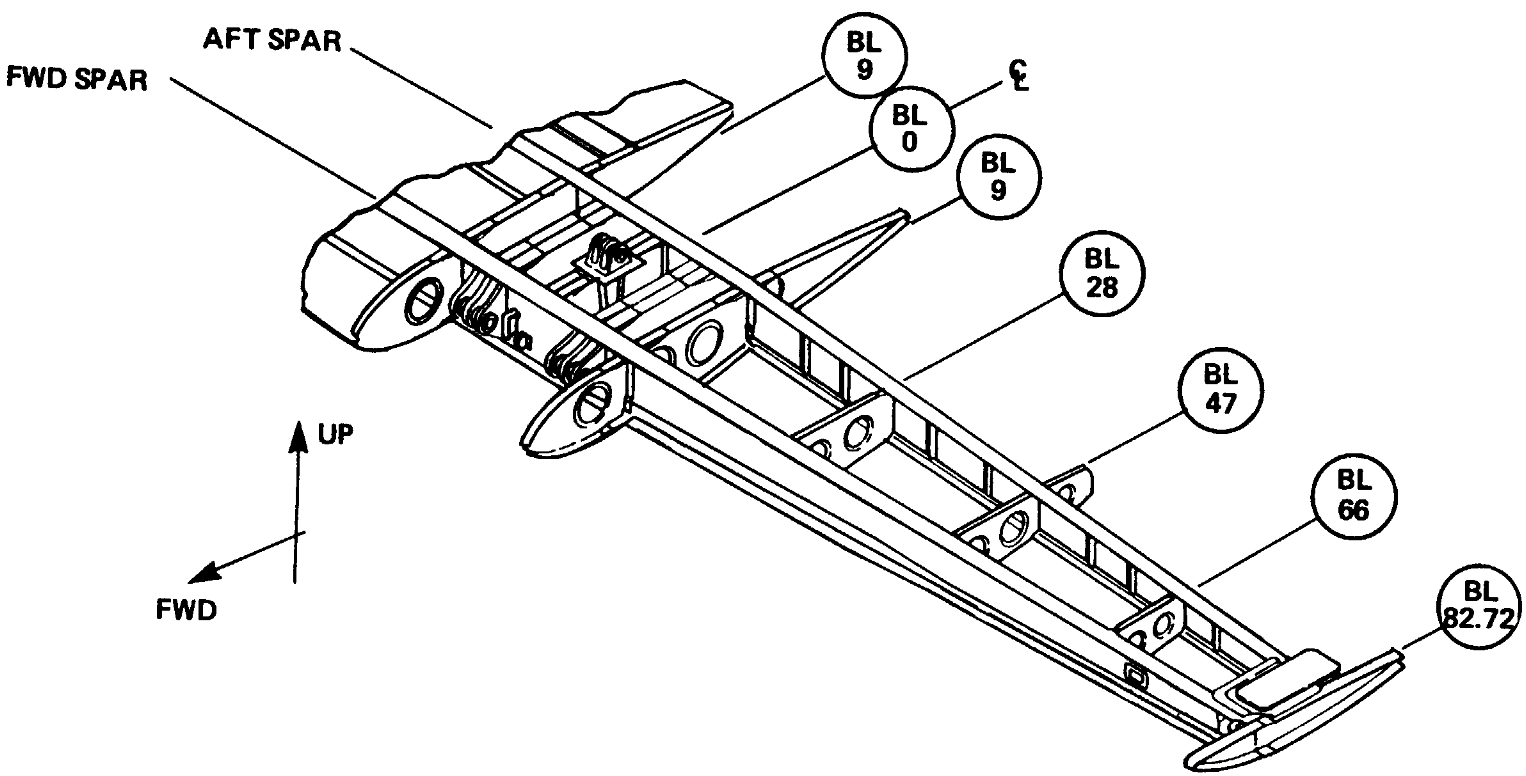
UH–60A STABILATOR
Structural Arrangement

The primary structure of the stabilator is a two spar box beam supported at the hinge line forward of the front spar and a hydraulic actuator at BL 0 between the front and rear spars. The hinges are located at BL 0.14m (5.4 in.) on both the right and left hand sides. The stabilator is symmetric about BL 0.0 with formed sheet metal ribs at Buttlines 0.23m (9 in.), 0.71m (28 in.), 1.19m (47 in.), 1.68m (66 in.), and 2.10M (82.72 in.). Built–up ribs are provided at BL 0 and ± .14m (5.4 in.) to distribute concentrated loads from the stabilator attachment fittings.

UH–60A STABILATOR

Structural Arrangement



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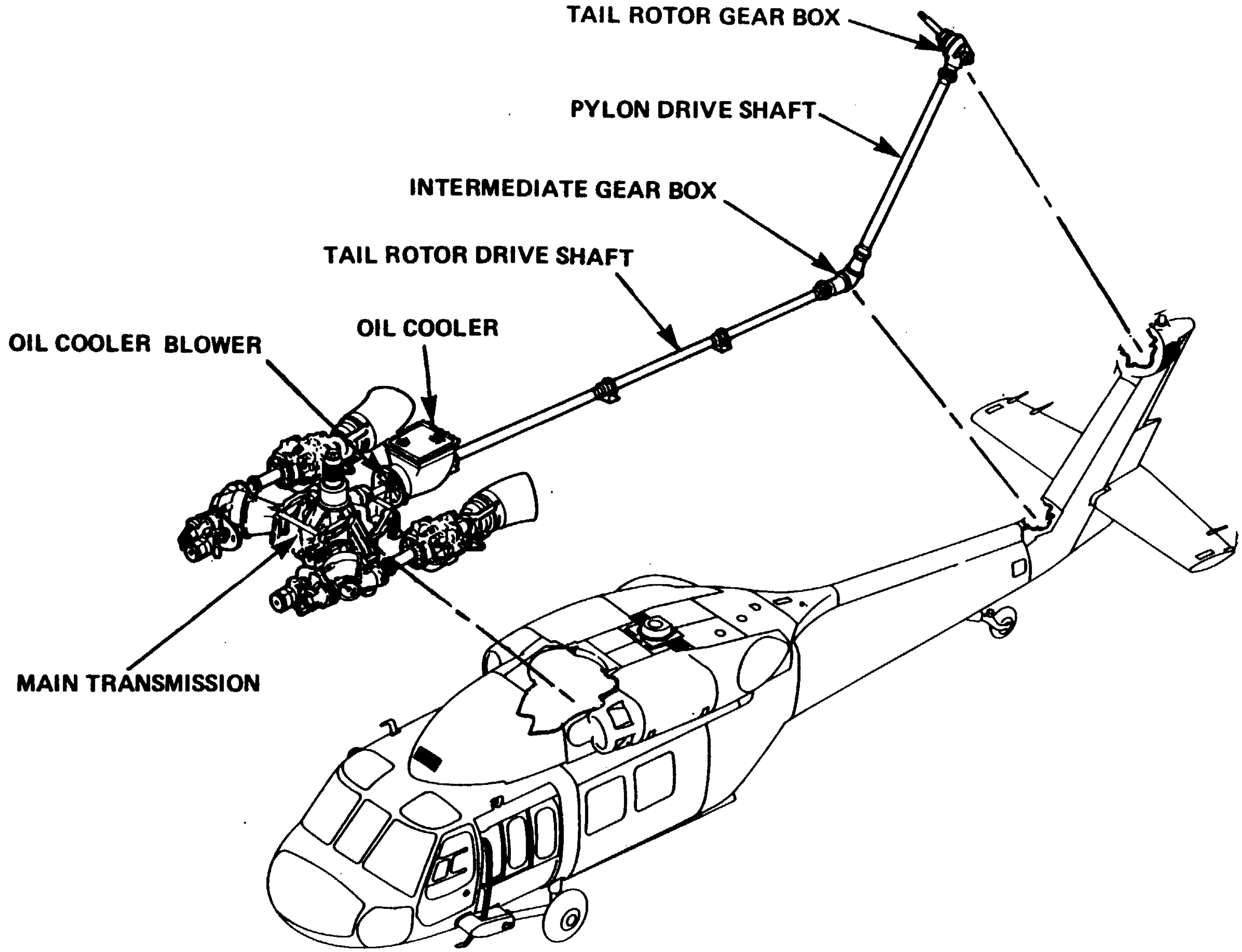
UH-60A POWER AND DRIVE TRAIN SYSTEMS

The figure shows the UH-60A power and drive train systems and the locations of the components of the systems.

The components are:

- Main Transmission
- Oil Cooler Blower
- Oil Cooler
- Tail Rotor Drive Shaft
- Intermediate Gear Box
- Pylon Drive Shaft
- Tail Rotor Gearbox

UH-60A POWER AND DRIVE TRAIN SYSTEMS



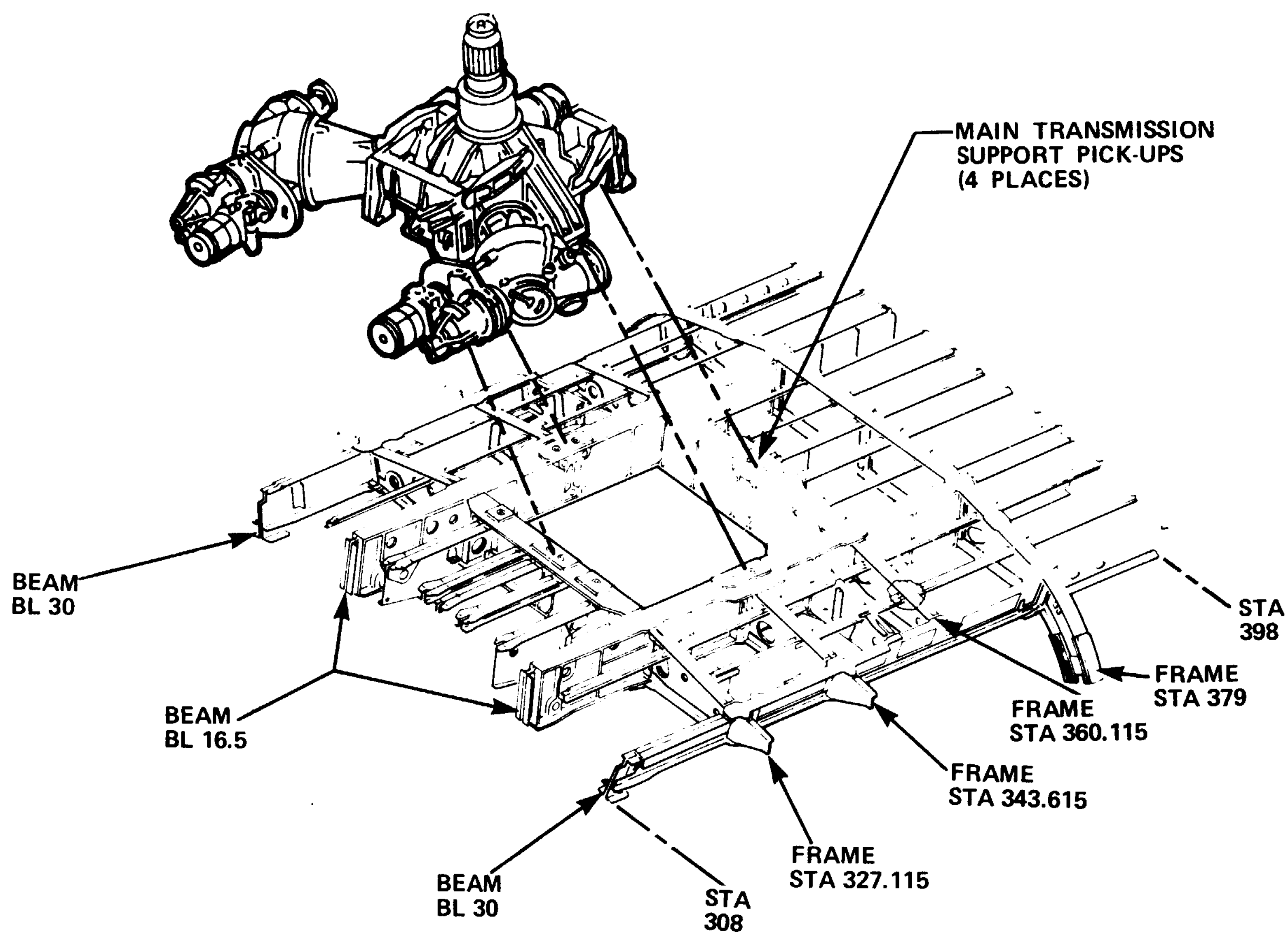
UNITED TECHNOLOGIES SIKORSKY AIRCRAFT

UH-60A MAIN TRANSMISSION SUPPORT STRUCTURE

The main transmission is attached to the fuselage at four points, each consisting of two 15.88 mm (0.625 in.) diameter bolts, for a total of eight bolts. The support points are located at BL 0 on the frames at Stations 8.31 m (327 in.) and 9.14 m (360 in.) and at Station 8.71 m (343 in.) on the left and right BL 0.42 m (16.5 in.) beams. The frames and beams at the transmission pickup points are machined aluminum fittings with integral barrel nuts to accommodate the attachment bolts.

The machined portions of the transmission beams at ± BL 0.42 m (16.5 in.) are continuous from Stations 7.82 m (308 in.) to 9.63 m (379 in.), and are redundantly supported by the four primary fuselage frames at Stations 7.49 m (295 in.), 7.82 m (308 in.), 9.63 m (379 in.), and 10.11 m (398 in.). Their primary purpose is to distribute the transmission and rotor head loads into the fuselage.

UH-60A MAIN TRANSMISSION SUPPORT STRUCTURE

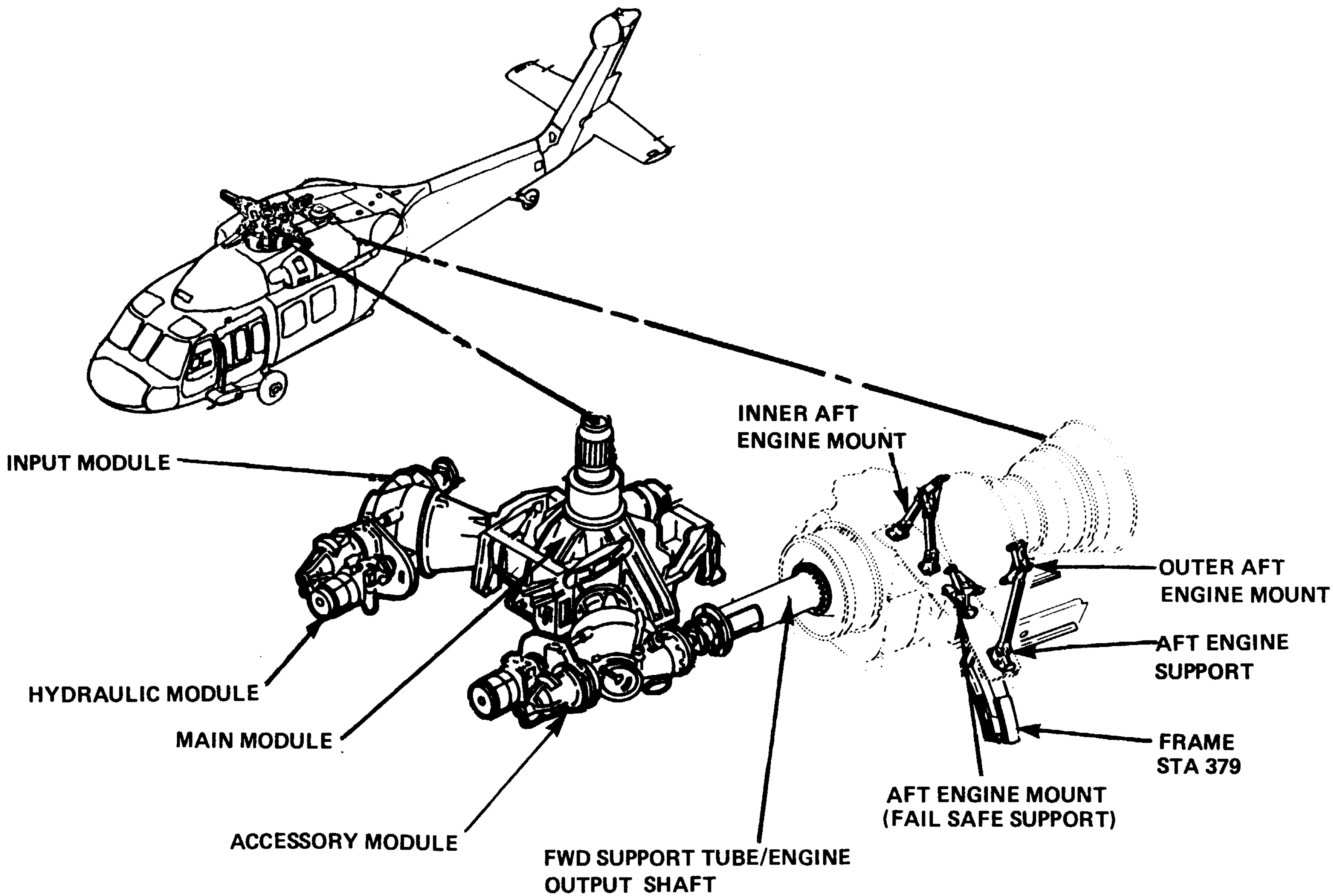


UNITED TECHNOLOGIES SIKORSKY AIRCRAFT

UH–60A ENGINE MOUNTS

The accompanying figure shows mounting arrangement of the General Electric T–700 turbine engines. The engine output shaft extends forward from the engine to the input module of the main transmission. This provides forward support for the engine and reacts side, vertical, and drag loads. The aft mount, which consists of a linkage arrangement, reacts side and vertical loads only. The lower aft engine mount is a fail–safe pick–up that only reacts load if one of the other aft links has failed.

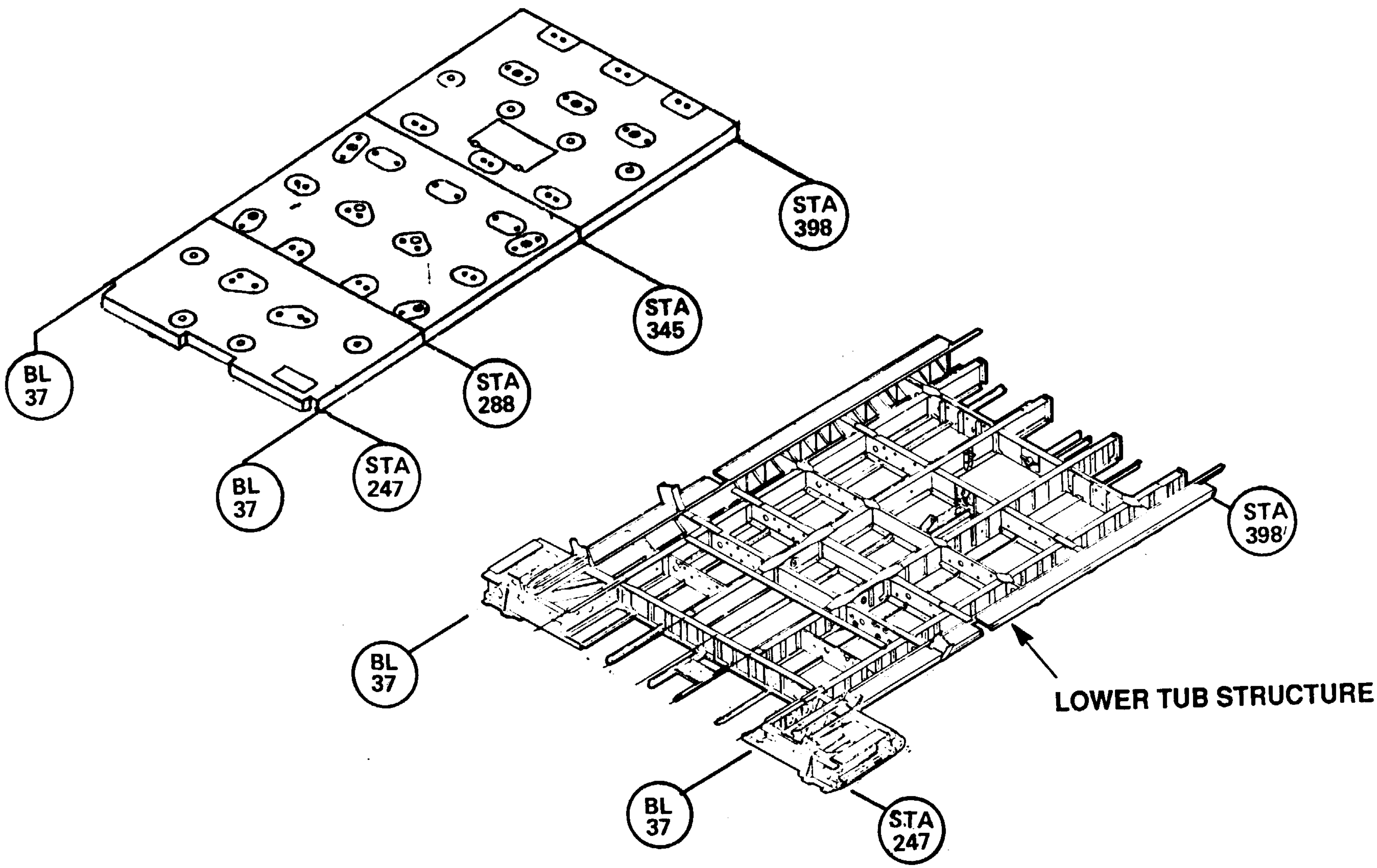
UH-60A ENGINE MOUNTS



UH-60A CABIN FLOOR

The cabin floor extends from Stations 6.27 m (247 in.) to 10.11 m (398 in.). It is divided longitudinally at Stations 7.32 m (288 in.) and 8.79 m (345 in.) into three sections. All panels are of similar construction consisting of unidirectional "E" glass upper skin and a woven fiberglass lower skin with a 19 mm (0.75 in.) thick nomex core. The floor sections, which are removable, are fastened to the frames and beams of the lower tub structure by corrosion resistant steel screws. Seat pan pick-ups and cargo ring pans attach at various locations throughout the floor.

UH-60A CABIN FLOOR

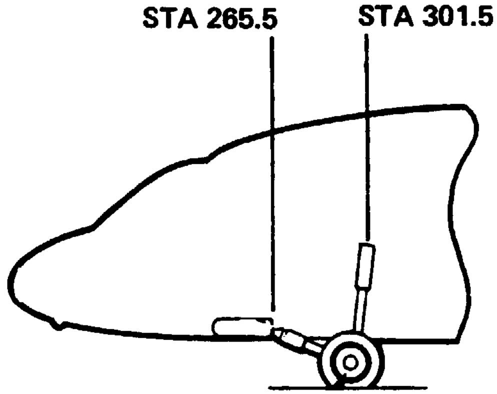


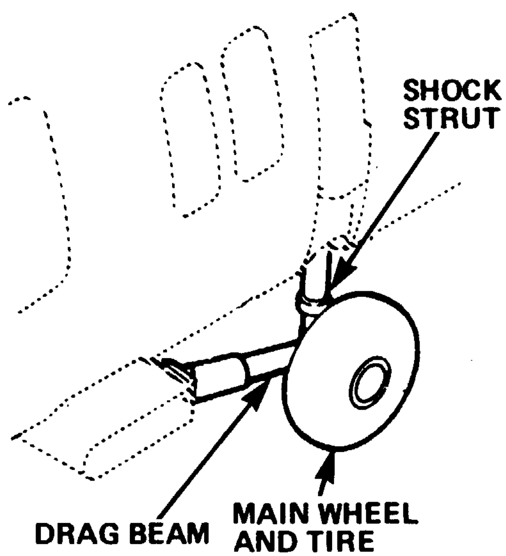
UNITED TECHNOLOGIES SIKORSKY AIRCRAFT

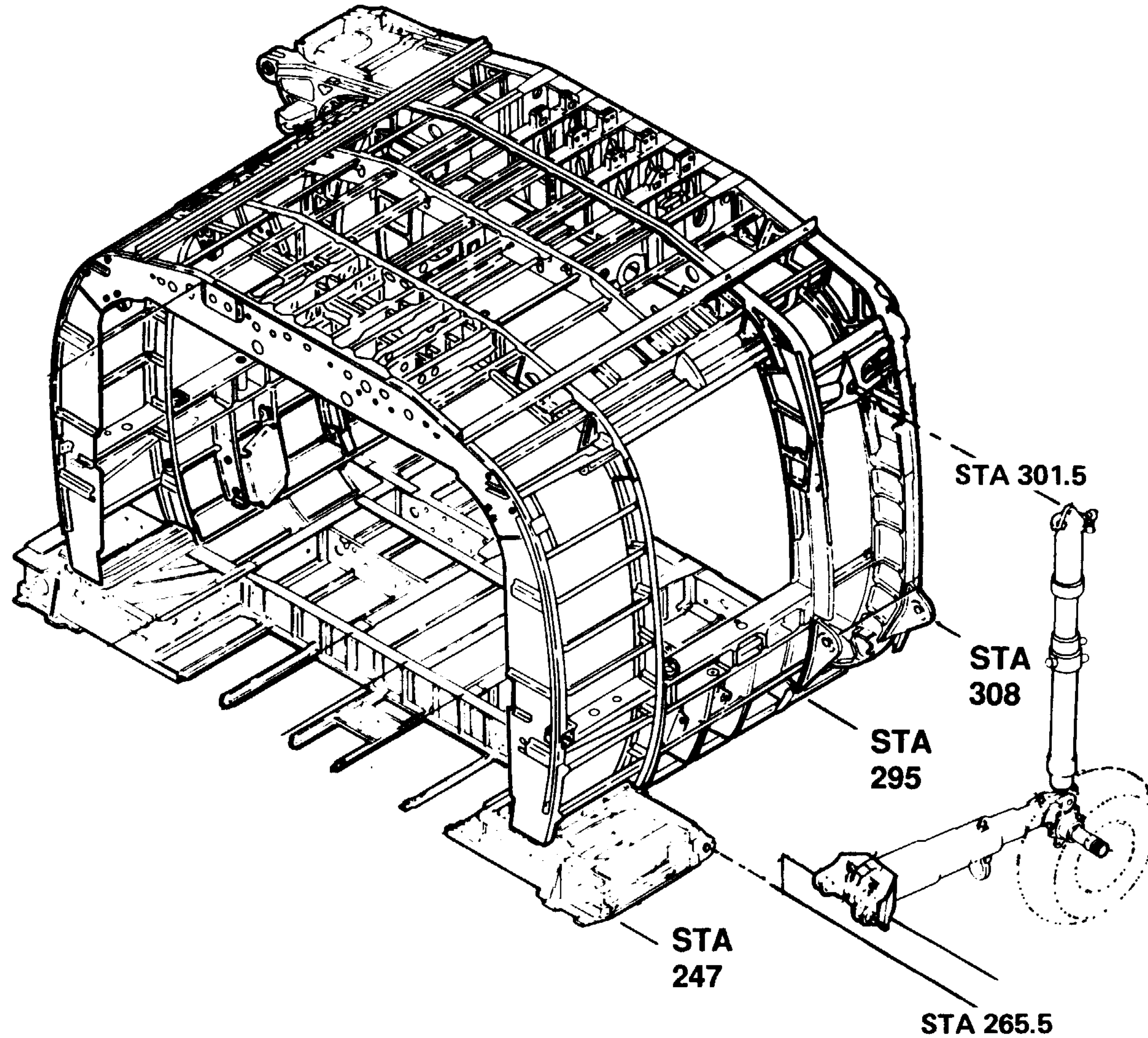
UH-60A MAIN LANDING GEAR

The UH-60A main landing gear is a crashworthy energy absorbing gear that will stroke at a constant load for high impact crash conditions. The oleo strut picks up the fuselage at Station 7.66 m (301.5 in.) via a machined aluminum fitting. The fitting beams the oleo loads to the primary fuselage frames at Stations 7.49 m (295 in.) and 7.82 m (308 in.) The drag beam which extends forward from the main wheel reacts all side and drag loads. It picks up lugs on the aft spar of the stub wing at Station 6.74 m (265.5 in.). The stub wing distributes the loads to the fuselage between Statios 6.27 m (247 in.) and 6.74 m (265.5 in.).

UH-60A MAIN LANDING GEAR





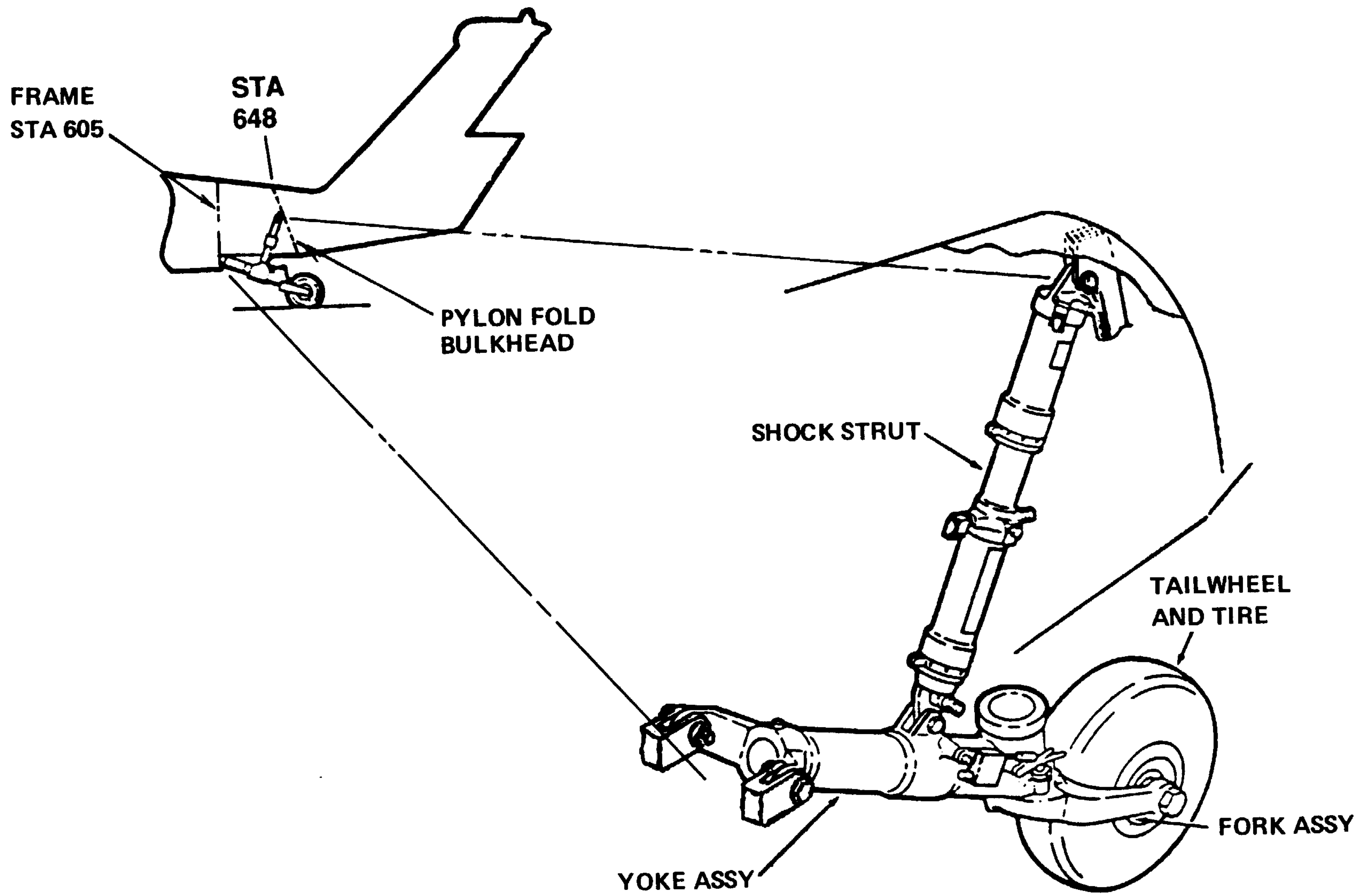


UNITED TECHNOLOGIES SIKORSKY AIRCRAFT

UH-60A TAIL LANDING GEAR

The UH-60A tail landing gear is an energy absorbing, crashworthy gear that will stroke at a constant load for high impact conditions. The oleo strut extends upward and aft and picks up the forward fold bulkhead at Station 16.46 m (648 in.). The bulkhead is a machined fitting that shears the gear loads into the tailcone. The yoke assembly extends forward and attaches to a machined fitting that comprises the lower portion of the Station 15.37 m (605 in.) bulkhead. All the landing gear side loads are introduced to the fuselage at Station 15.37 m (605 in.).

UH-60A TAIL LANDING GEAR

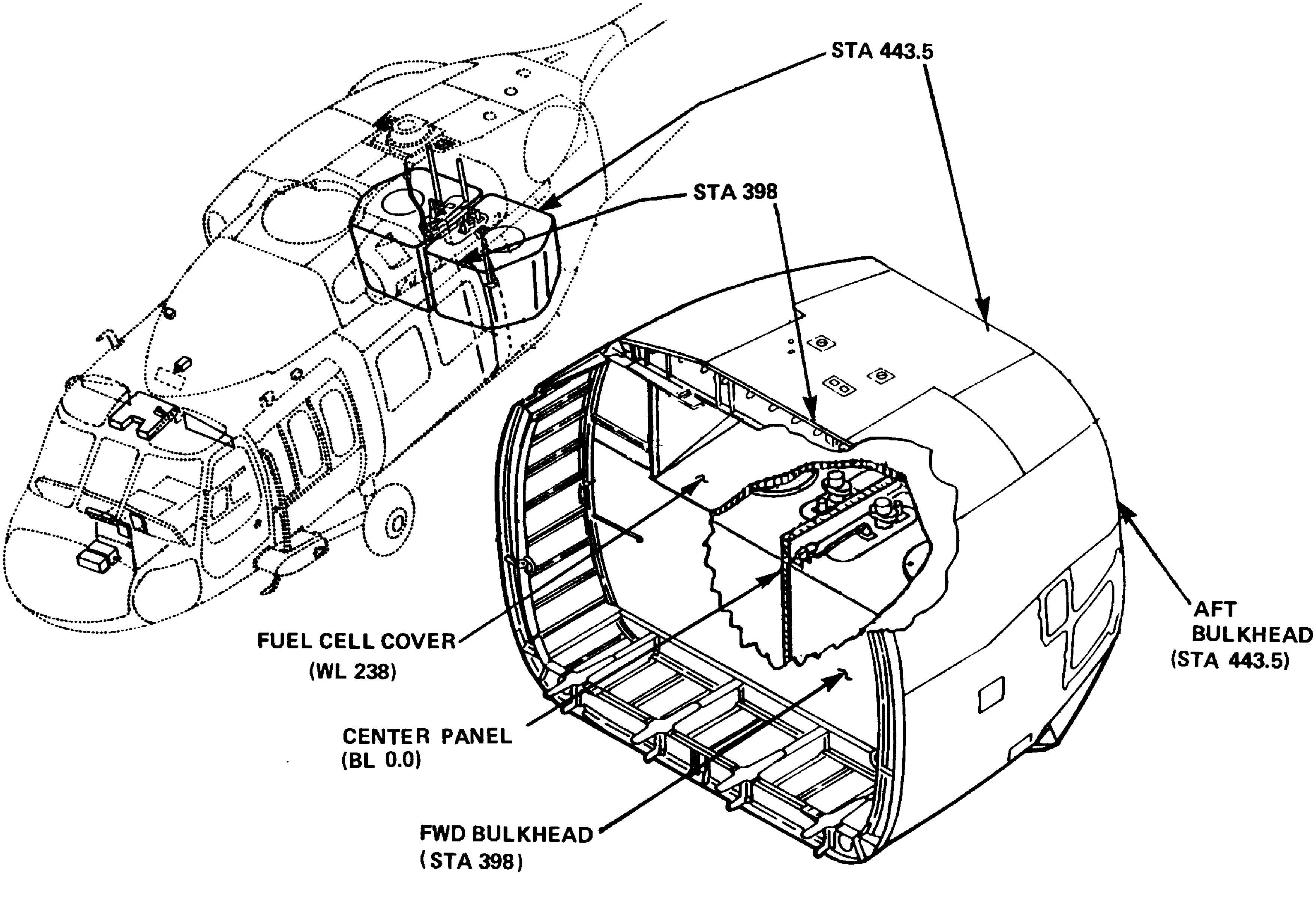


UNITED TECHNOLOGIES SIKORSKY AIRCRAFT

UH-60A FUEL BAY

The two fuel cells are situated symmetrically about BL 0.0, below WL 6.05 m (238 in.), and extend between the bulkheads at Stations 10.11 m (398 in.) and 11.26 m (443.5 in.). Pressure loads on the bulkheads are reacted by vertical beams at approximately .15 m (6 in.) pitch that consist of 0.05 m (2 in.) deep extruded aluminum channel sections. Inboard acting pressure loads are reacted by a 0.025 m (1 in.) thick, fiberglass faced honeycomb center panel. The panel is supported at the upper and lower edges and by the bulkheads at Stations 10.11 m (398 in.) and 11.26 m (443.5 in.). The top of each cell is supported by a deck at WL 6.05 m (238 in.). The decks are of honeycomb construction with aluminum faces, and a removable access panel is provided in each. The bottom and outboard sides of the cells are supported by four sheet metal frames equally spaced between the bulkheads and by the lower beams at Buttlines 0.25 m (10 in.) and 0.76 m (30 in.) on each side.

UH–60A FUEL BAY

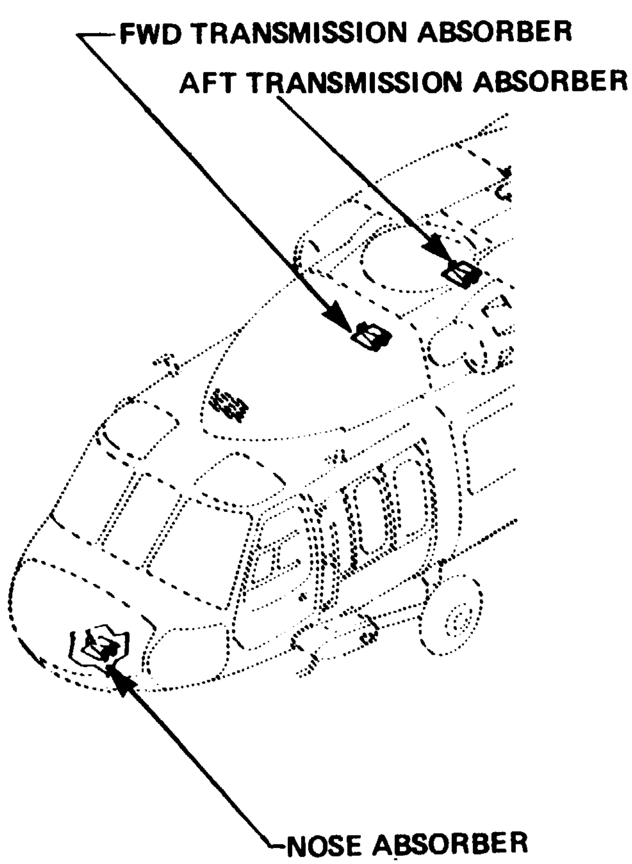


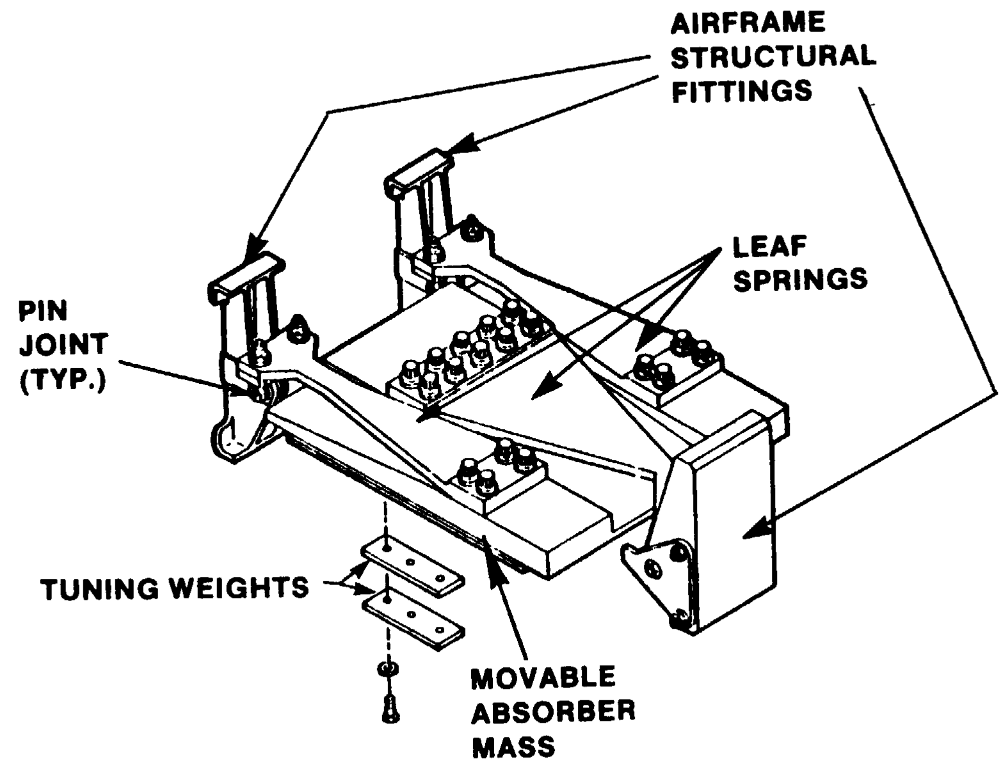
UNITED TECHNOLOGIES SIKORSKY AIRCRAFT

UH-60A VIBRATION ABSORBERS

The UH-60A has three vibration absorbers. Two of the absorbers are located on the underside of the cabin roof, immediately forward and aft of the main transmission and the third is located on the underside of the cockpit floor. The purpose of the absorbers is to reduce the 4/rev vertical vibrations at the cockpit and cabin. They do this by introducing new modes, which respond so as to cancel the existing modal response at the desired frequency and location. Each absorber consists of a movable mass attached to three leaf springs, which in turn are pin-connected to airframe fittings.

UH-60A VIBRATION ABSORBERS





TYPICAL ABSORBER ASSEMBLY

UNITED TECHNOLOGIES SIKORSKY AIRCRAFT

UH–60A WEIGHTS SUMMARY

The accompanying figure summarizes the weight breakdown of the UH–60A for the empty and design gross weights.

UH–60A WEIGHTS SUMMARY

ITEM	WEIGHT KG	WEIGHT LB
Rotor Group	658	1,451
Tail Group	180	396
Body Group	904	1,992
Alighting Gear Group	212	467
Engine Section	104	230
Propulsion Group (Incl. Drive Systems)	1,329	2,930
Flight Control Group	433	954
Auxiliary Power Plant Group	80	177
Instruments Group	79	175
Hydraulic & Pneumatic Group	69	152
Electrical Group	171	377
Avionics Group	184	405
Armament Group	16	35
Furnishing & Equipment Group	463	1,021
Air Conditioning Group	23	50
Anti–Icing Group	38	84
Loads and Handling Group	24	52
WEIGHT EMPTY	4,967	10,948
FIXED USEFUL LOAD	428	872
FUEL	1,060	2,338
PAYLOAD	1,177	2,667
DESIGN GROSS WEIGHT	7,632	16,825

UNITED TECHNOLOGIES SIKORSKY AIRCRAFT

SECTION 4.0
MODELING GUIDES

MODELING GUIDES
Introduction

This section summarizes the approach that is to be used in formulating the static, mass, and vibration models for the UH–60A airframe. Its purpose is to develop a set of guidelines which describe the procedures to be used to represent the components of the airframe within the capabilities of the NASTRAN program. Specific guidelines are given for: identification of structure not modeled; node and element numbering conventions; treatment of frames, stringers, skin, and internal structure such as floor and bulkheads; engine and engine mounts: representation of power and drive train components; representation of concentrated and distributed mass items, and changes required to convert the statics model to the vibration model.

MODELING GUIDES

Introduction

Guidelines are given for preparing the static, mass, and vibration finite element models including:

- Identification of structure not modeled
- Node and element numbering conventions
- Frame, stringer, and skin treatment
- Internal structure; e.g. floors and bulkheads
- Engine and engine mounts
- Drive train components
- Concentrated and distributed masses
- Changes from statics to vibration model

SECTION 4.1
STATIC MODELING

STATIC MODELING
Breakdown into Subassemblies

For the purpose of static modeling, the helicopter is divided into seven subassemblies. These seven subassemblies, which generally follow those used in manufacturing the aircraft, are:

1. COCKPIT:
   Station 4.11 m (162 in.) to Station 6.27 m (247 in.); this section contains the avionics compartment and the pilot and copilot seats.

2. CABIN:
   Station 6.27 m (247 in.) to Station 9.63 m (379 in.); this section includes the main landing gears, engines, main transmission, main rotor drive shaft, and cabin floor.

3. MAIN ROTOR PYLON:
   Above W.L. 6.83 m (269 in.); this section consists of the engine firewalls, the protective aerodynamic fairings and covers and includes the main rotor head. This subassembly, with the exception of the main rotor head, is considered to be all secondary structure and is not modeled.

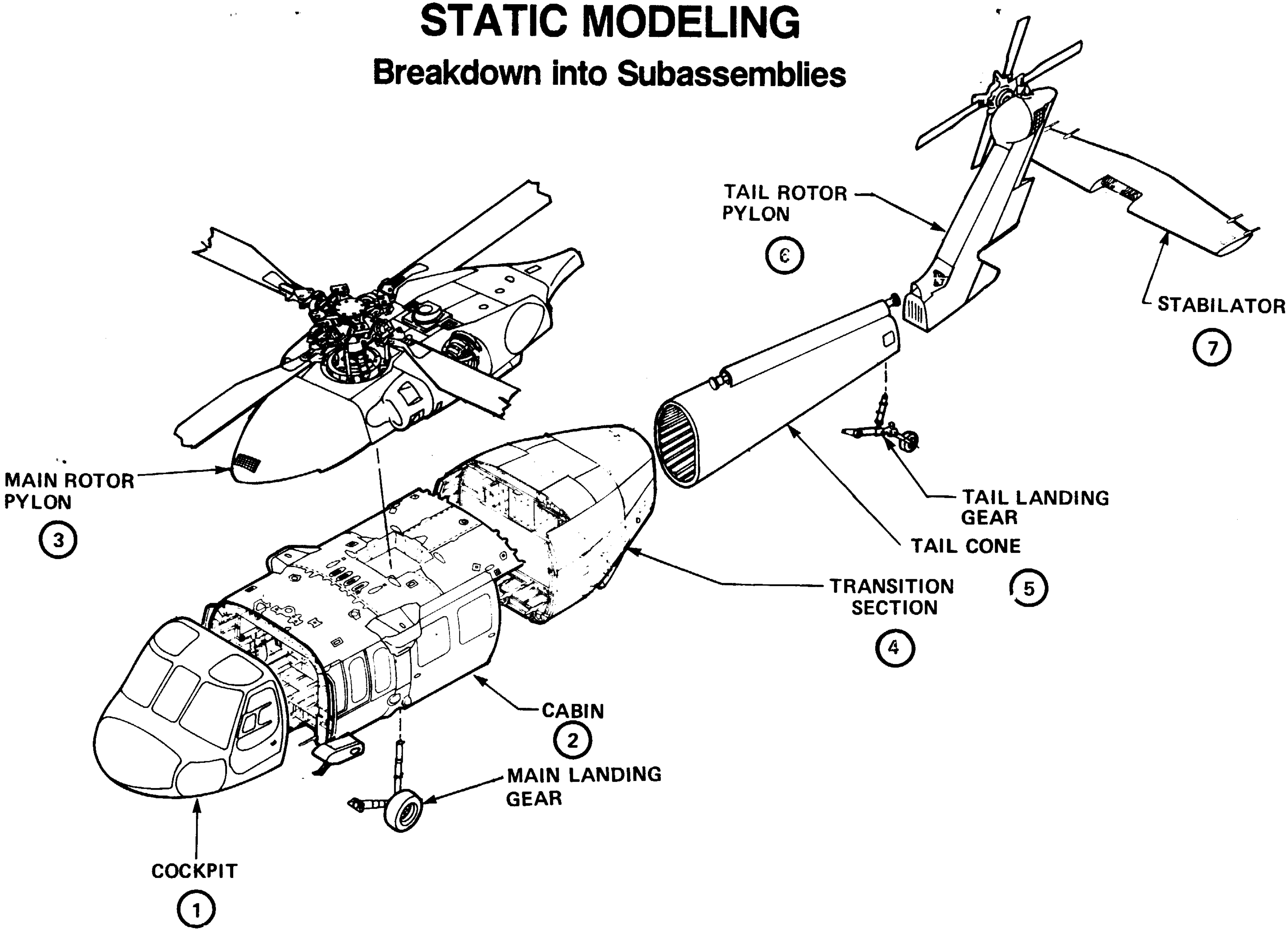
4. TRANSITION SECTION:
   Station 9.63 m (379 in.) to Station 12.32 m (485 in.); this section includes the fuel cells, fuel cell compartments, and equipment stowage compartments.

5. TAILCONE:
   Station 12.32 m (485 in.) to Station 16.45 m (647.5 in.); this section includes the tail landing gear, tail rotor drive shaft and tail rotor drive shaft cover.

6. TAIL ROTOR PYLON:
   Aft of Station 16.45 m (647.5 in.); this section includes the intermediate gear box, tail rotor drive shaft, tail rotor gear box and, tail rotor assembly.

7. STABILATOR:
   At W.L. 6.21 m (244.4 in.)

STATIC MODELING
Breakdown into Subassemblies



UNITED TECHNOLOGIES SIKORSKY AIRCRAFT

STATIC MODELING
Node Number Assignment

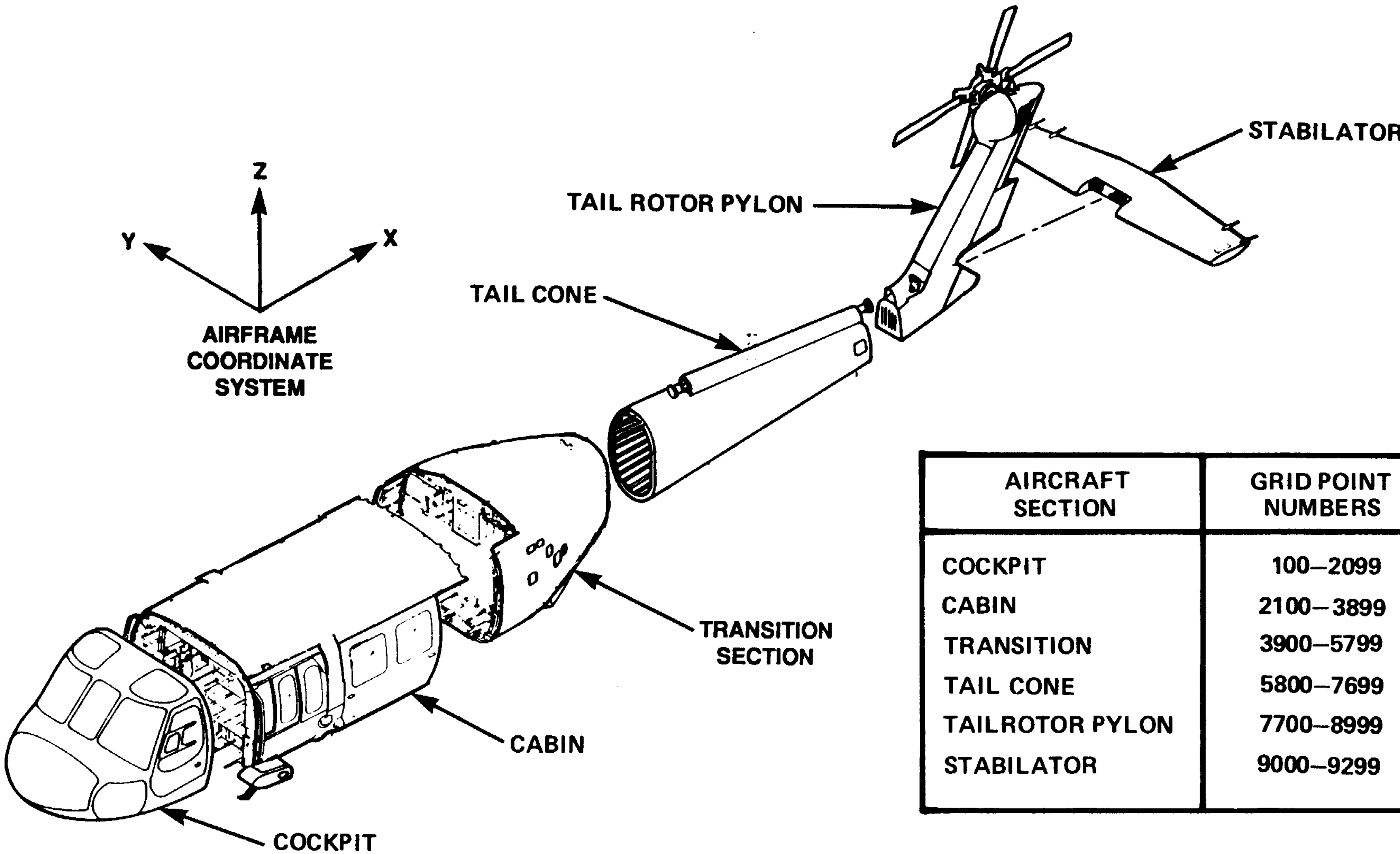
Sikorsky Aircraft currently uses a convention for labeling both grid points and elements which provides a logical means for locating each grid point in the model and identifying all elements connected to it. The first key to this convention is that the grid points are assigned in easily identifiable patterns. The second key is that elements are numbered using a convention in which the element number indicates the type of element, its direction with respect to the axes of the airframe coordinate system, and the first defined grid point on the connectivity card for the element.

The accompanying figure indicates the range of node numbers assigned to each of the six major subassemblies of the aircraft which are to be modeled. At the common boundaries between subassemblies, grid point numbers are used from the subassembly with the lower grid point numbers.

The element numbering convention, which is described in detail in the next figure, makes pre–assignment of element numbers to each subassembly unnecessary.

Subsequent figures provide examples of the grid point and element numbering conventions for major structural assemblies.

STATIC MODELING
Node Number Assignment



AIRCRAFT SECTION	GRID POINT NUMBERS
COCKPIT	100–2099
CABIN	2100–3899
TRANSITION	3900–5799
TAIL CONE	5800–7699
TAILROTOR PYLON	7700–8999
STABILATOR	9000–9299

UNITED TECHNOLOGIES SIKORSKY AIRCRAFT

STATIC MODELING
Element Numbering Convention

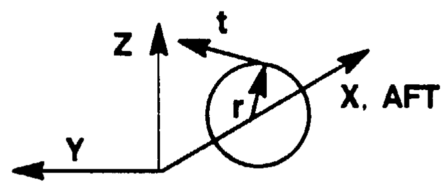
The table in the accompanying figure defines the convention that is used to label the elements in the NASTRAN model of the UH–60A.

Element identification numbers consist of six digit numbers. The first digit is a prefix indicating the type of element, as defined by the second row in the table. For example, a QUAD4 would have a number 6 for the first digit. BAR and CONROD elements use two different element prefixes to differentiate between elements used in the outer shell from those used for internal structure.

The second digit indicates the direction of the element. For BAR and CONROD elements the direction of the element is defined to be the axis of the element, for planar elements it is the direction of the positive normal to the element. The directional prefix usually will have a value of 1, 2, or 3, depending on whether the direction of the element is parallel to the x, y, or z coordinate axes of the airframe. Values of 4, 5, and 6, or 7, 8, or 9 may also be used to denote that the axis of an element is parallel to the x, y, and z axes, respectively, in cases where two or more elements of the same type are connected to the same node and are roughly parallel to the same coordinate axis. BAR and CONROD elements representing frames on the outer shell and planar elements representing the outer shell skin are considered to be special cases and have zero for a directional prefix.

The remaining four digits denote the first defined grid point on the connectivity card for the element. Element connectivity is specified in a manner so that the positive directions of the axes of the element coordinate system are in the directions of the positive axes of the airframe coordinate system. An exception is for a BAR or CONROD element representing a frame on contour where the axial direction is defined counterclockwise looking aft, and the positive normal direction for a planar element is defined as pointing inward.

STATIC MODELING
Element Numbering Convention



ELEMENT NUMBER ZYXXXX

Z = ELEMENT PREFIX
Y = DIRECTIONAL PREFIX
XXXX = NUMBER OF FIRST DEFINED GRID POINT

ELEMENT TYPE		BAR	BAR	CONROD	CONROD	SHEAR	QUAD4	TRIA3
ELEMENT PREFIX		1	2	3	4	5	6	7
	ELEMENT AXIS OR NORMAL	DIRECTIONAL PREFIX						
OUTER SHELL	X	–	1	–	1	–	–	–
	t	–	O	–	O	O	O	O
BULKHEADS/ FRAMES	X	–	–	–	–	1,4,7,	1,4,7	1,4,7
	Y	2,5,8	–	2,5,8	–	–	–	–
	Z	3,6,9	–	3,6,9	–	–	–	–
WEBS/ BUTTLINE BEAMS	X	1,4,7	–	1,4,7	–	–	–	–
	Y	–	–	–	–	2,5,8	2,5,8	2,5,8
	Z	3,6,9	–	3,6,9	–	–	–	–
FLOORS	X	1,4,7	–	1,4,7	–	–	–	–
	Y	2,5,8	–	2,5,8	–	–	–	–
	Z	–	–	–	–	3,6,9	3,6,9	3,6,9

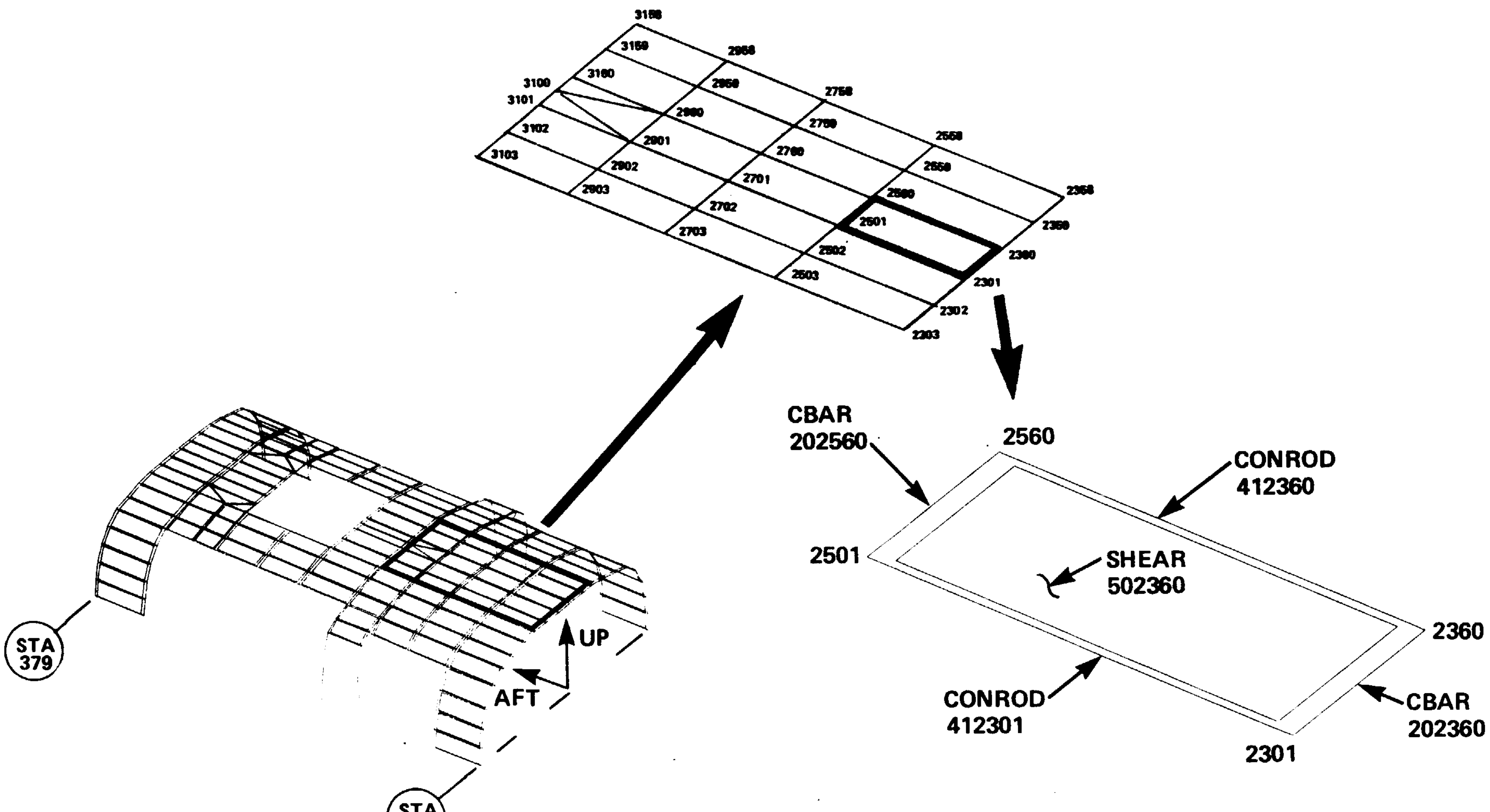
UNITED TECHNOLOGIES SIKORSKY AIRCRAFT

STATIC MODELING
Node and Element Numbering Convention
Outer Shell

The accompanying figure illustrates the node and element numbering convention that is to be followed for the outer shell. Two hundred numbers are allocated for the grid points on the outer shell and in the interior for each frame station represented in the model. Grid point numbering starts in the cockpit, with the first frame station assigned the numbers 100 to 299, the second 300 to 499, and so on down the longitudinal axis of the airframe. Frames are numbered counterclockwise looking aft, starting with the grid point of the stringer closest to BL 0.0 in the counterclockwise direction. The last two digits of the grid point numbers are kept the same along common stringer lines.

Connectivity for BAR or CONROD elements representing frames on contour is defined so that the axial direction for the element is positive in the counterclockwise direction. Connectivity for BAR or CONROD elements representing buttline beams or stringers on contour is defined so that the axial direction is positive when it points aft. Connectivity for planar elements is defined so that the positive direction of the element x–axis points counterclockwise around the adjacent forward frame, and the element z–axis points inboard.

STATIC MODELING
Node and Element Numbering Convention
Outer Shell



CABIN ROOF STRUCTURE

STATIC MODELING
Node and Element Numbering Convention
Frames and Bulkheads

Built-up frames in the UH-60A are represented in the NASTRAN model with RODS and SHEAR elements. Machined frames for the UH-60A are usually represented in the NASTRAN model with BAR elements on contour. However, several machined frames, because of their structural arrangement, have also been idealized using ROD and SHEAR elements. The accompanying figure illustrates both types of idealization.

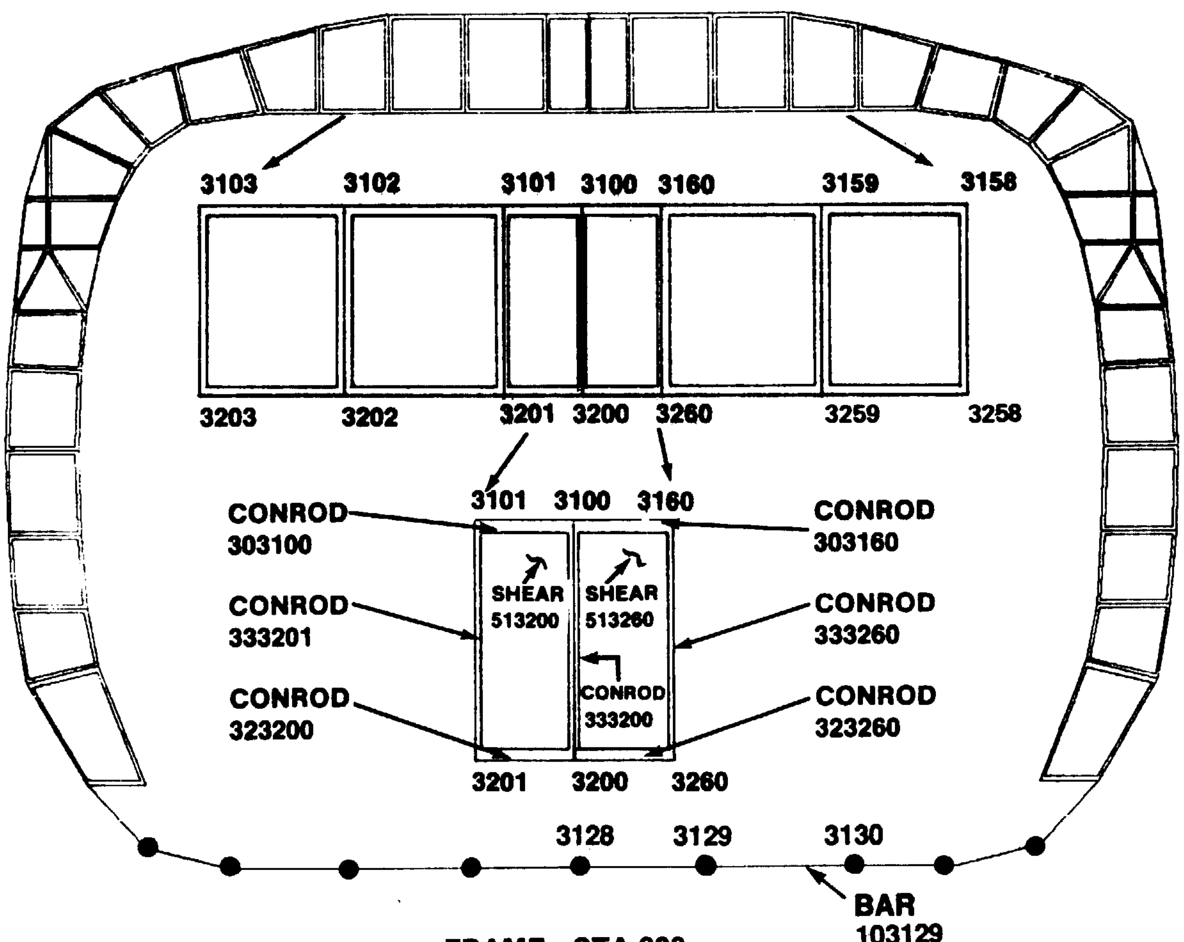
Irrespective of the method of idealization, grid points and elements on contour follow the conventions described in the previous figure for the outer shell. Interior grid points for the frame are incremented by 100 from the connected grid point on the outer shell.

Connectivity for CONRODs representing the inner cap is specified so that the axial direction is positive in the counterclockwise direction, looking aft. The direction prefix for these elements is always 2, irrespective of the orientation of the element. Connectivity for CONRODs representing the web stiffeners is specified so that the axial direction is positive outboard. The directional prefix for these elements is always 3, irrespective of the orientation of the element. Connectivity for the planar elements is specified so that the positive normal points aft, and the element x-axis points counterclockwise when looking aft.

STATIC MODELING

Node and Element Numbering Convention

Frames and Bulkheads



FRAME - STA 308
(LOOKING AFT)

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STATIC MODELING
Node and Element Numbering Convention
Bulkheads

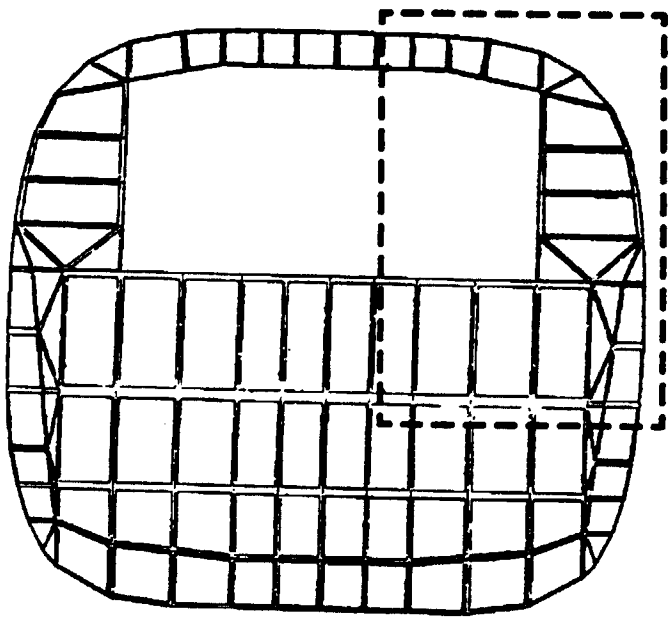
The accompanying figure illustrates the node and element numbering convention used for bulkheads. For grid points and elements on contour numbering conventions established for the outer shell are followed. Interior grid points are labeled with numbers which are the even multiples of 100 assigned to the frame station. When viewed from the front, the labeling of the grid points starts in the upper right corner and moves horizontally to the left along a waterline. The grid point labeling continues to the next lowest grid point on the right.

Connectivity for horizontal and vertical stiffeners is defined so that the positive axial directions for these elements point to the left and up, respectively. Connectivity for the planar elements is defined so that the positive normal points aft, and the element x–axis points left.

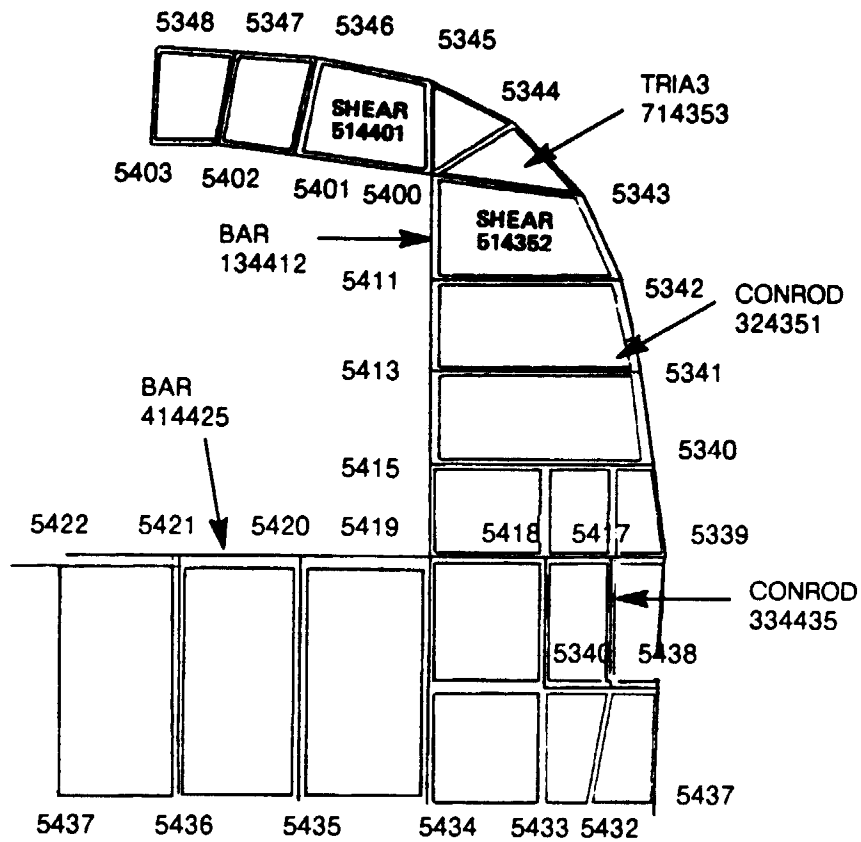
STATIC MODELING

Node and Element Numbering Convention

Bulkheads



BULKHEAD STA 443.5



UNITED TECHNOLOGIES SIKORSKY AIRCRAFT

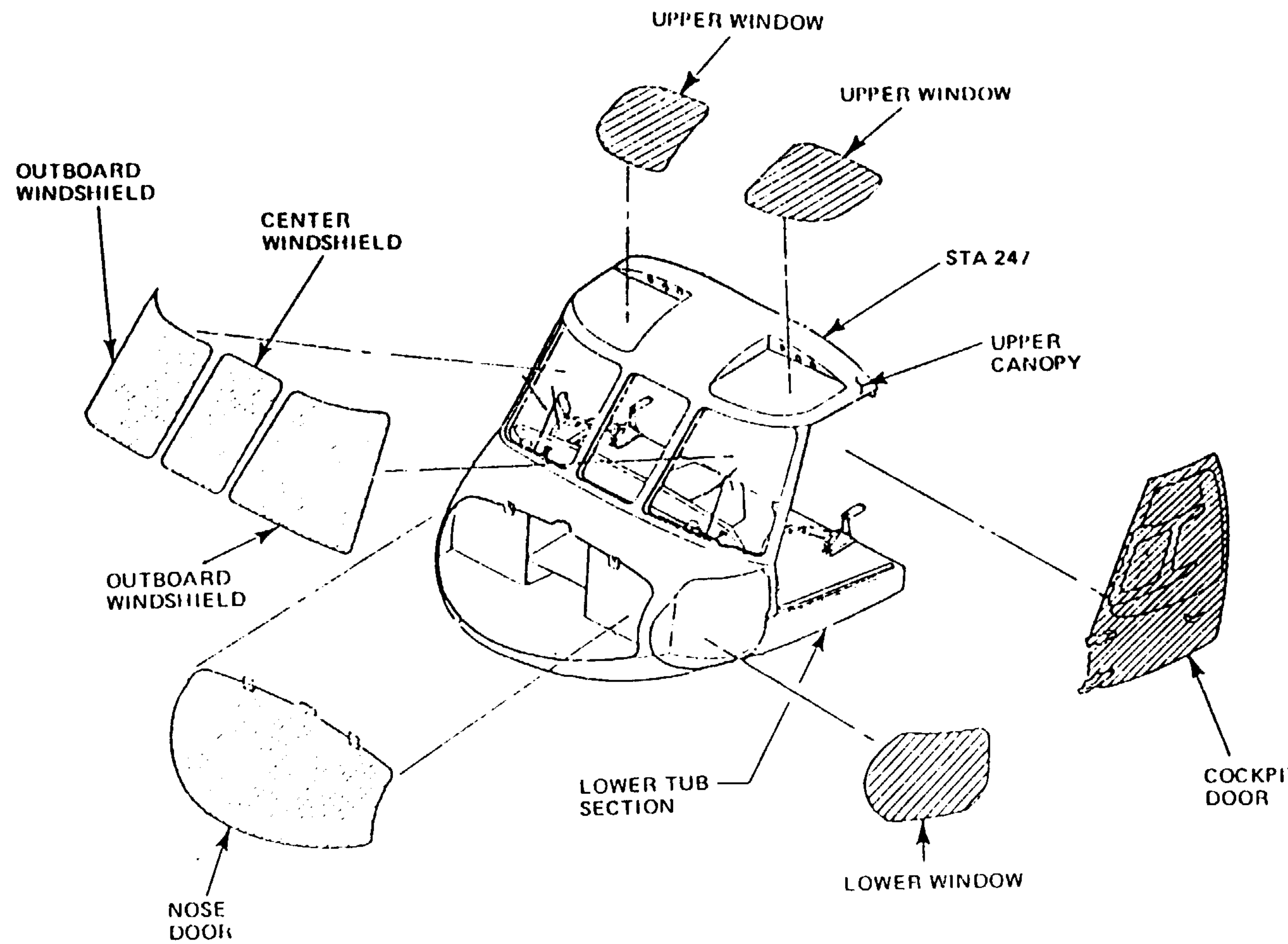
STATIC MODELING
Structure Not Modeled - Cockpit

Parts in the cockpit section not to be modeled as structure include:

1) Upper Windows
2) Windshields
3) Lower Windows
4) Avionics Nose Door
5) Cockpit Doors

STATIC MODELING

Structure Not Modeled – Cockpit



UNITED TECHNOLOGIES SIKORSKY AIRCRAFT

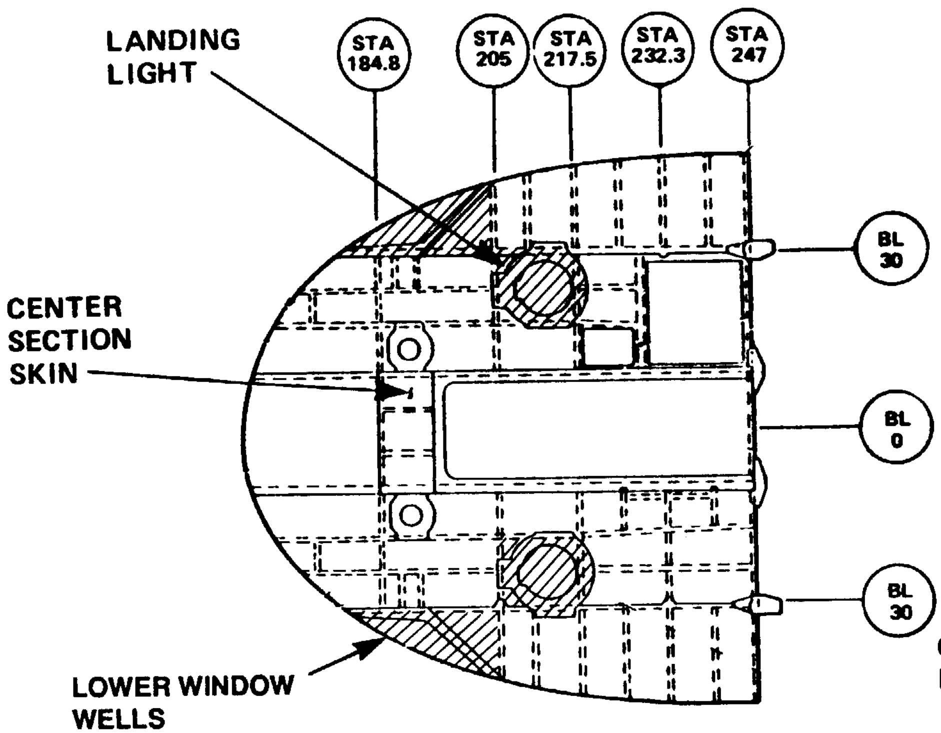
STATIC MODELING
Structure Not Modeled – Cockpit Plating and Cabin Floor

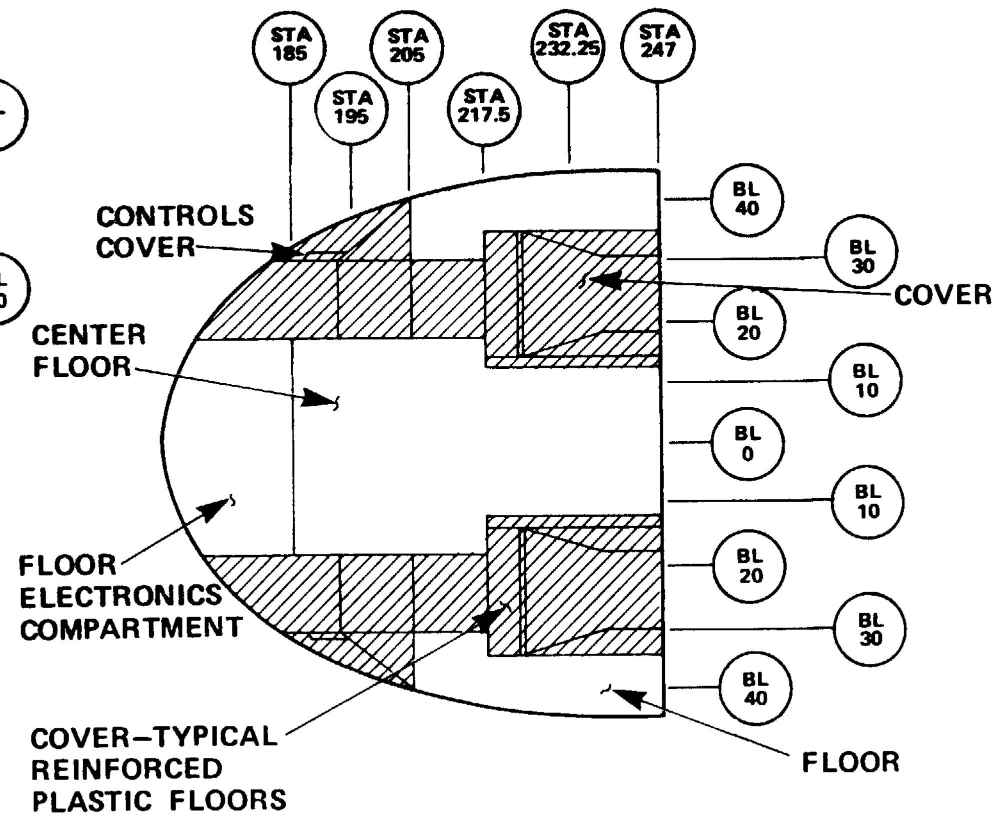
The accompanying figure shows additional parts in the cockpit section which are not modeled as structure. These include:

1) Lower Window Wells
2) Landing Light Frames and Panels
3) Floor Covers and Hatches

STATIC MODELING

Structure Not Modeled – Cockpit Plating and Cabin Floor





UNITED TECHNOLOGIES SIKORSKY AIRCRAFT

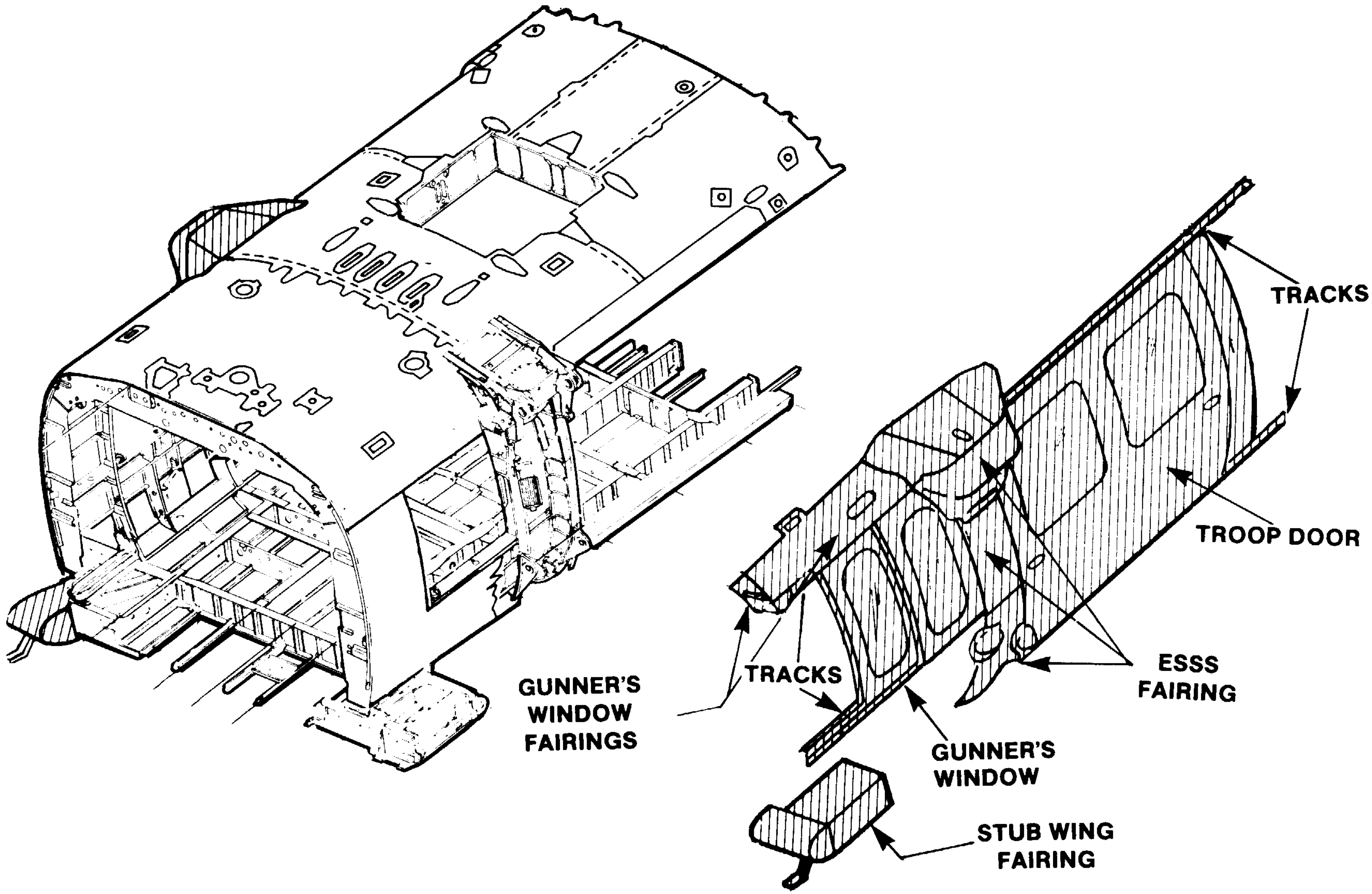
STATIC MODELING
Structure Not Modeled - Cabin

Parts in the cabin section not to be modeled as structure include:

1) Gunner's Window and Tracks
2) Gunner's Window Fairing
3) ESSS Fairings
4) Stub Wing Fairings
5) Troop Door and Tracks

STATIC MODELING

Structure Not Modeled - Cabin



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UNITED TECHNOLOGIES SIKORSKY AIRCRAFT

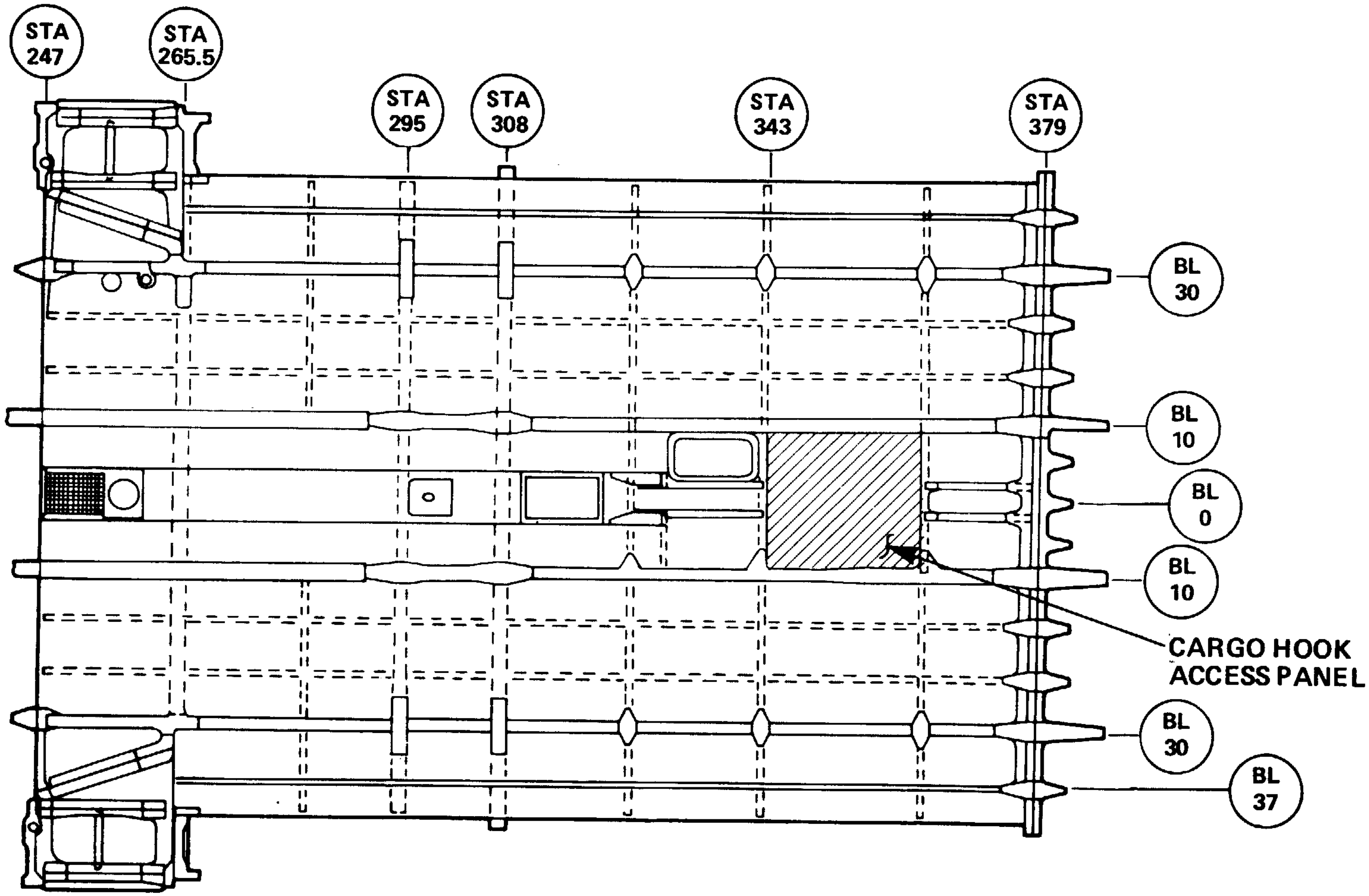
STATIC MODELING
Structure Not Modeled - Lower Cabin Tub

Additional parts of the cabin section not modeled as structure include:

1) Cargo Hook Access Panel

STATIC MODELING

Structure Not Modeled – Lower Cabin Tub



UNITED TECHNOLOGIES SIKORSKY AIRCRAFT

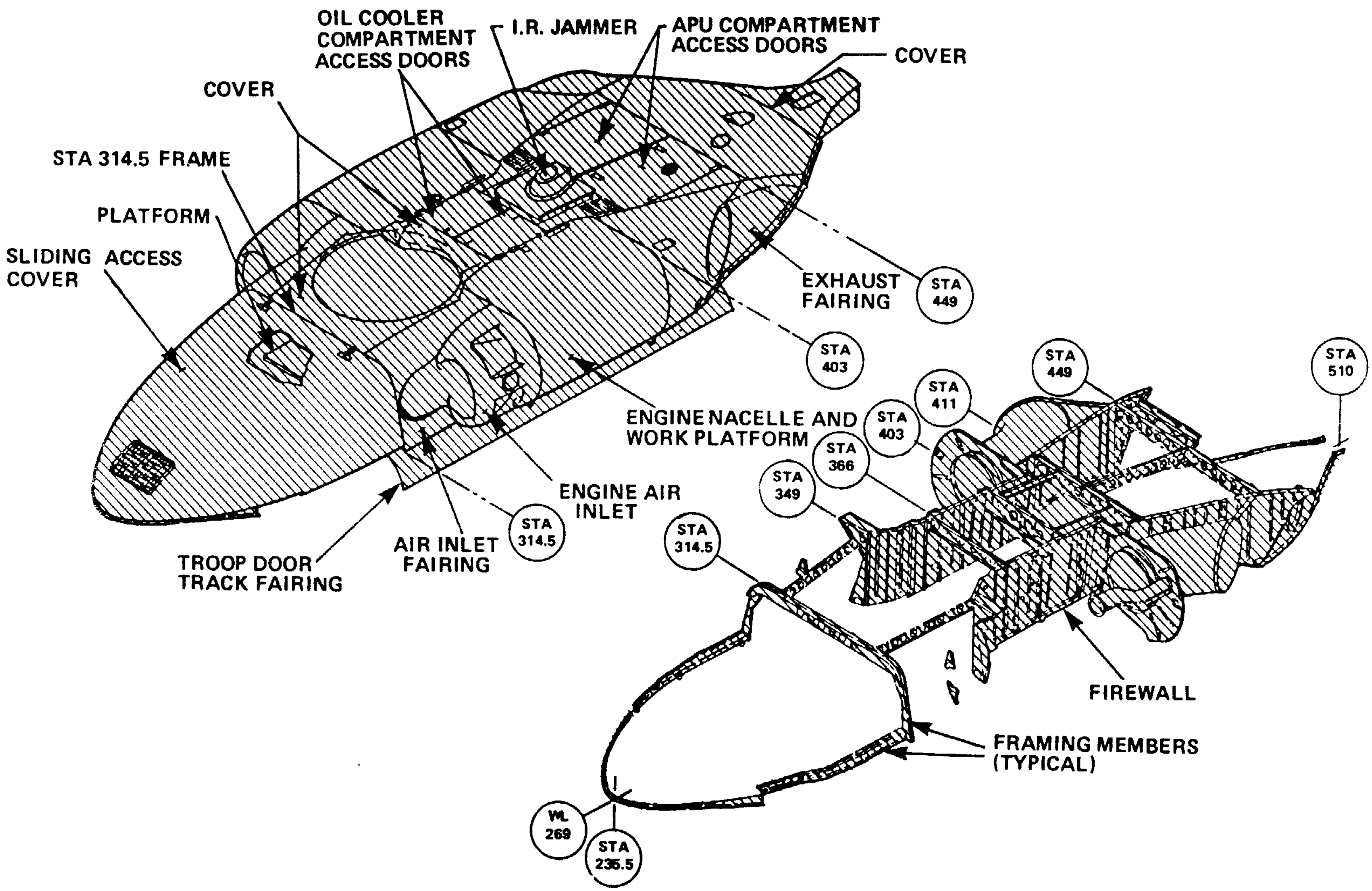
STATIC MODELING
Structure Not Modeled - Main Rotor Pylon

All parts of the main rotor pylon are secondary structure and are not modeled. These parts include:

1) Access Covers and Doors
2) Fairings
3) Engine Nacelle and Work Platform
4) Firewall
5) Main Rotor Pylon Framing Members

STATIC MODELING

Structure Not Modeled – Main Rotor Pylon



UNITED TECHNOLOGIES SIKORSKY AIRCRAFT

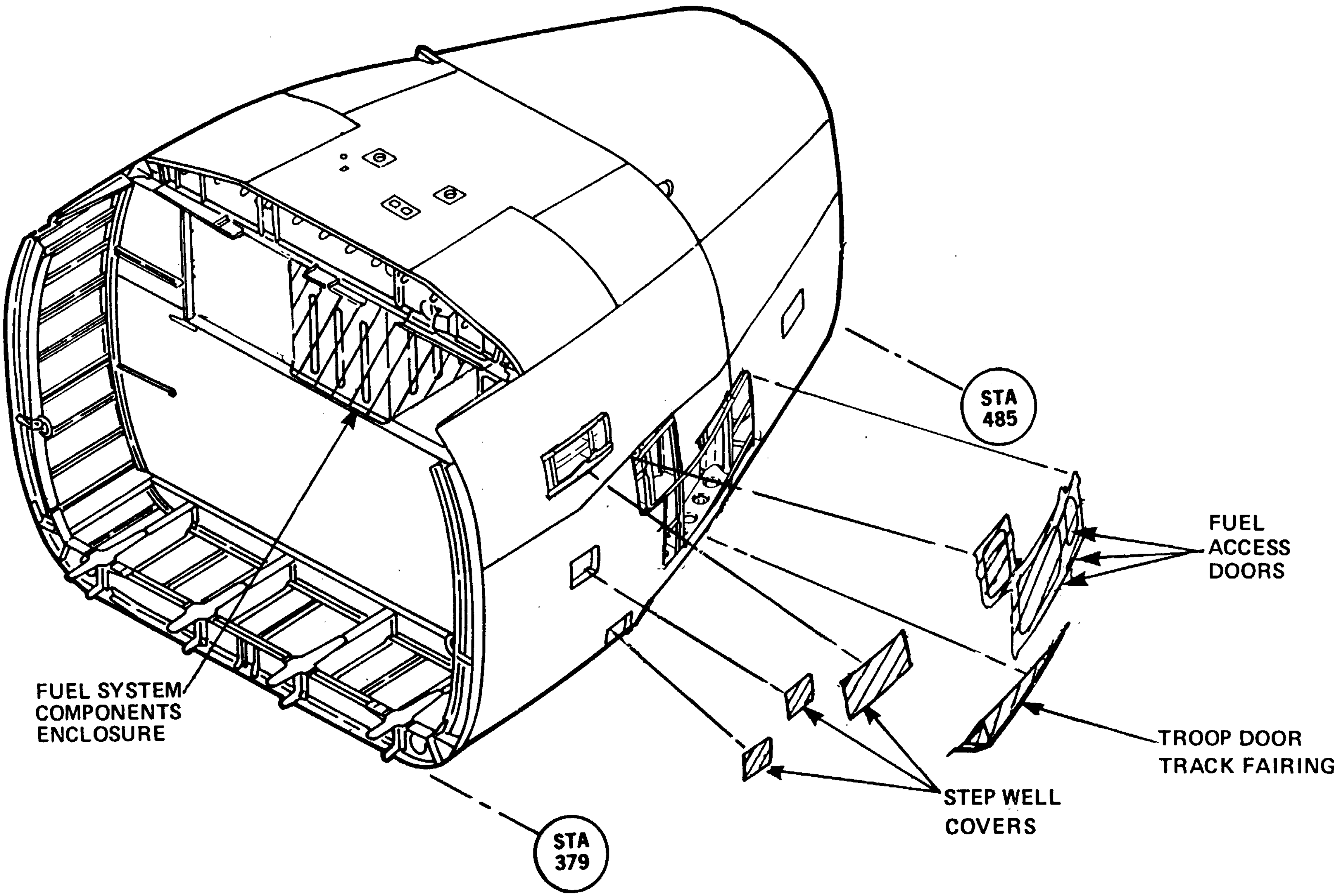
STATIC MODELING
Structure Not Modeled - Transition Section

Parts of the transition section which are not modeled as structure include:

1) Step Well Covers
2) Fuel Access Doors
3) Troop Door Track Fairings
4) Fuel System Components Enclosure

STATIC MODELING

Structure Not Modeled - Transition Section



UNITED TECHNOLOGIES SIKORSKY AIRCRAFT

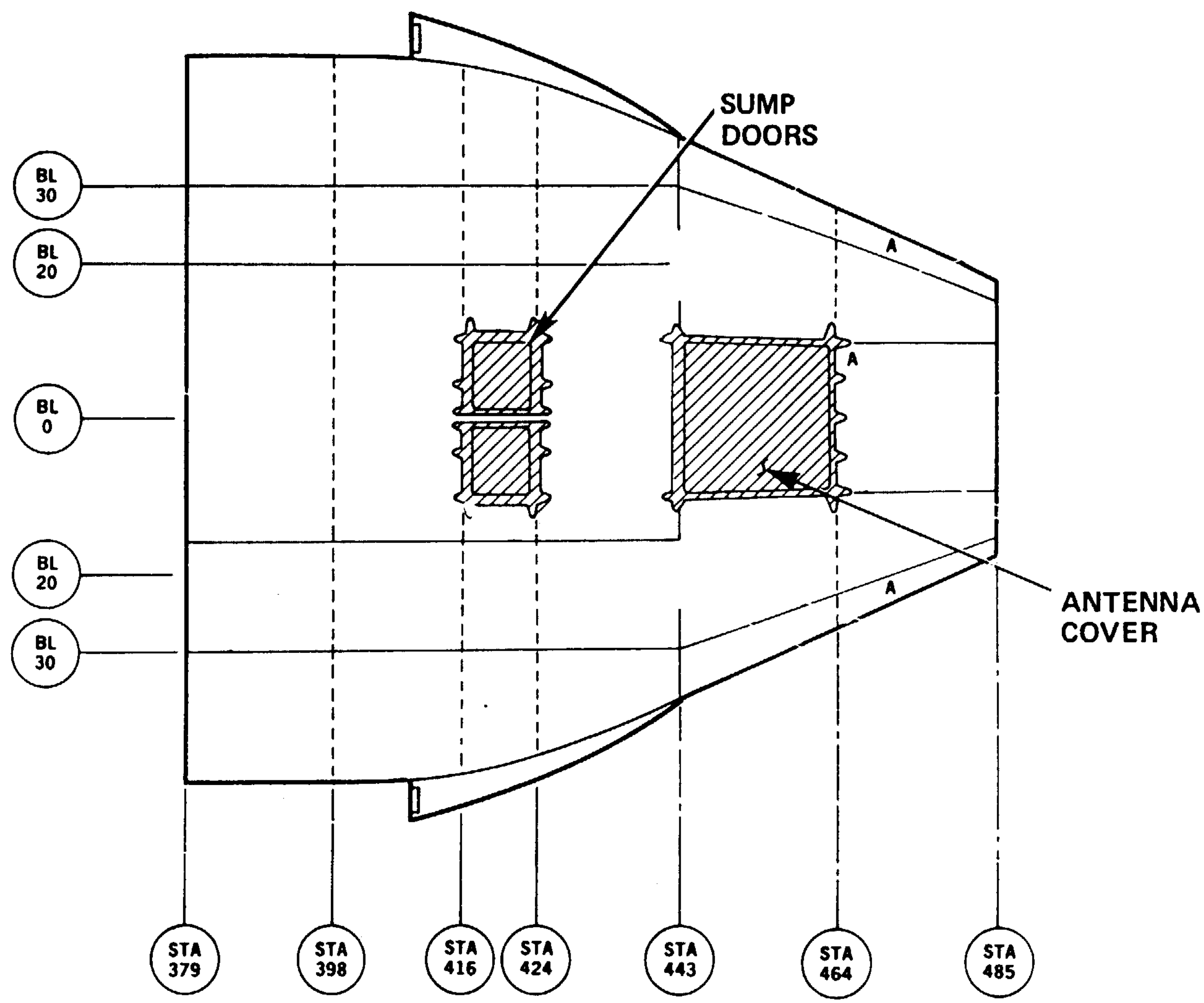
STATIC MODELING
Structure Not Modeled – Transition Section Bottom Plating

Additional parts of the transition section not modeled as structure include:

1) Fuel Bay Sump Doors
2) Antenna Cover

STATIC MODELING

Structure Not Modeled – Transition Section Bottom Plating



BOTTOM PLATING - LOOKING UP

UNITED TECHNOLOGIES SIKORSKY AIRCRAFT

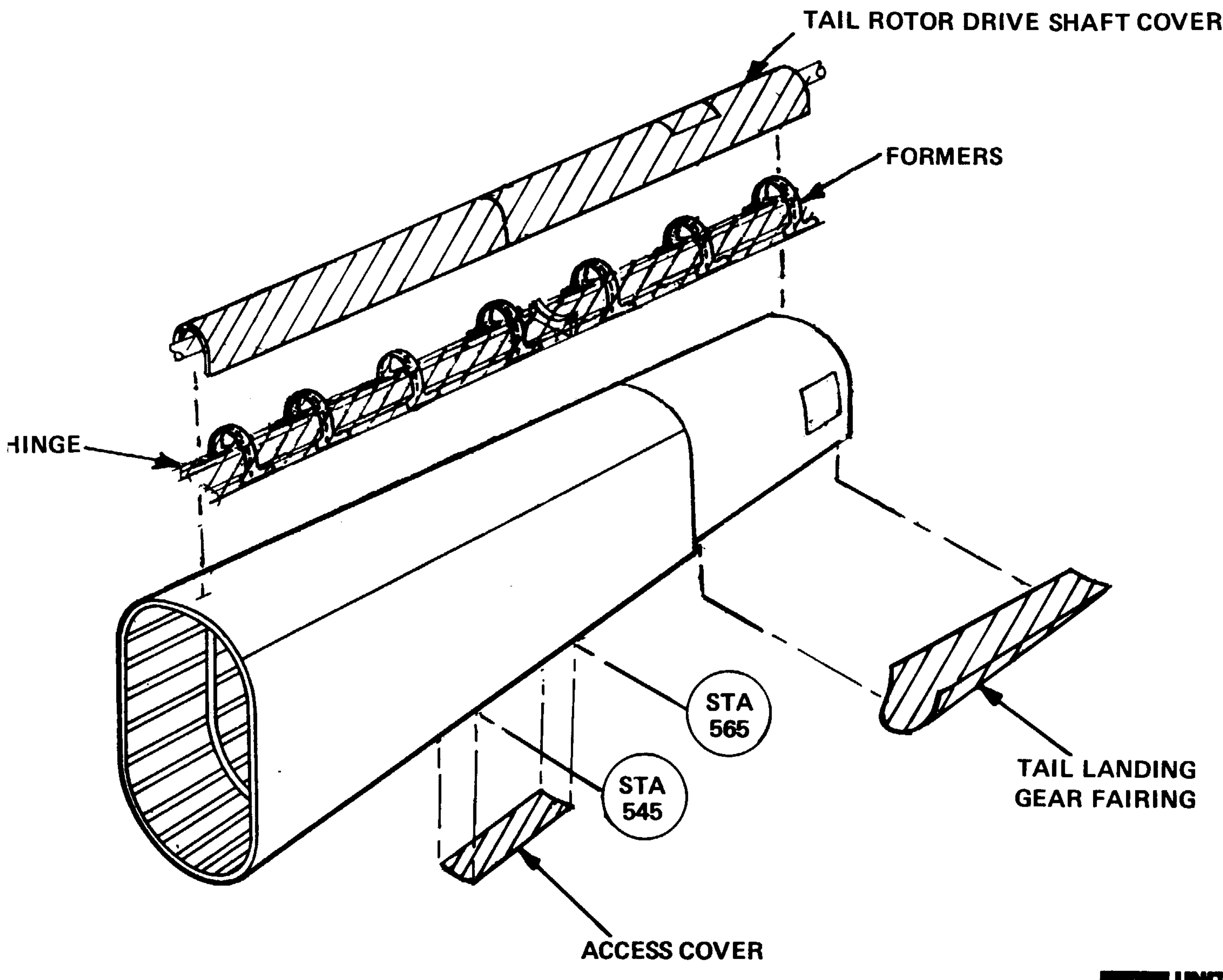
STATIC MODELING
Structure Not Modeled – Tailcone

Parts of the tailcone not modeled as structure include:

1) Tail Rotor Drive Shaft Cover
2) Tail Rotor Drive Shaft Cover Formers
3) Tail Rotor Drive Shaft Cover Hinge
4) Tail Rotor Drive Shaft
5) Lower Access Cover
6) Tail Landing Gear Fairing

STATIC MODELING

Structure Not Modeled – Tailcone



UNITED TECHNOLOGIES SIKORSKY AIRCRAFT

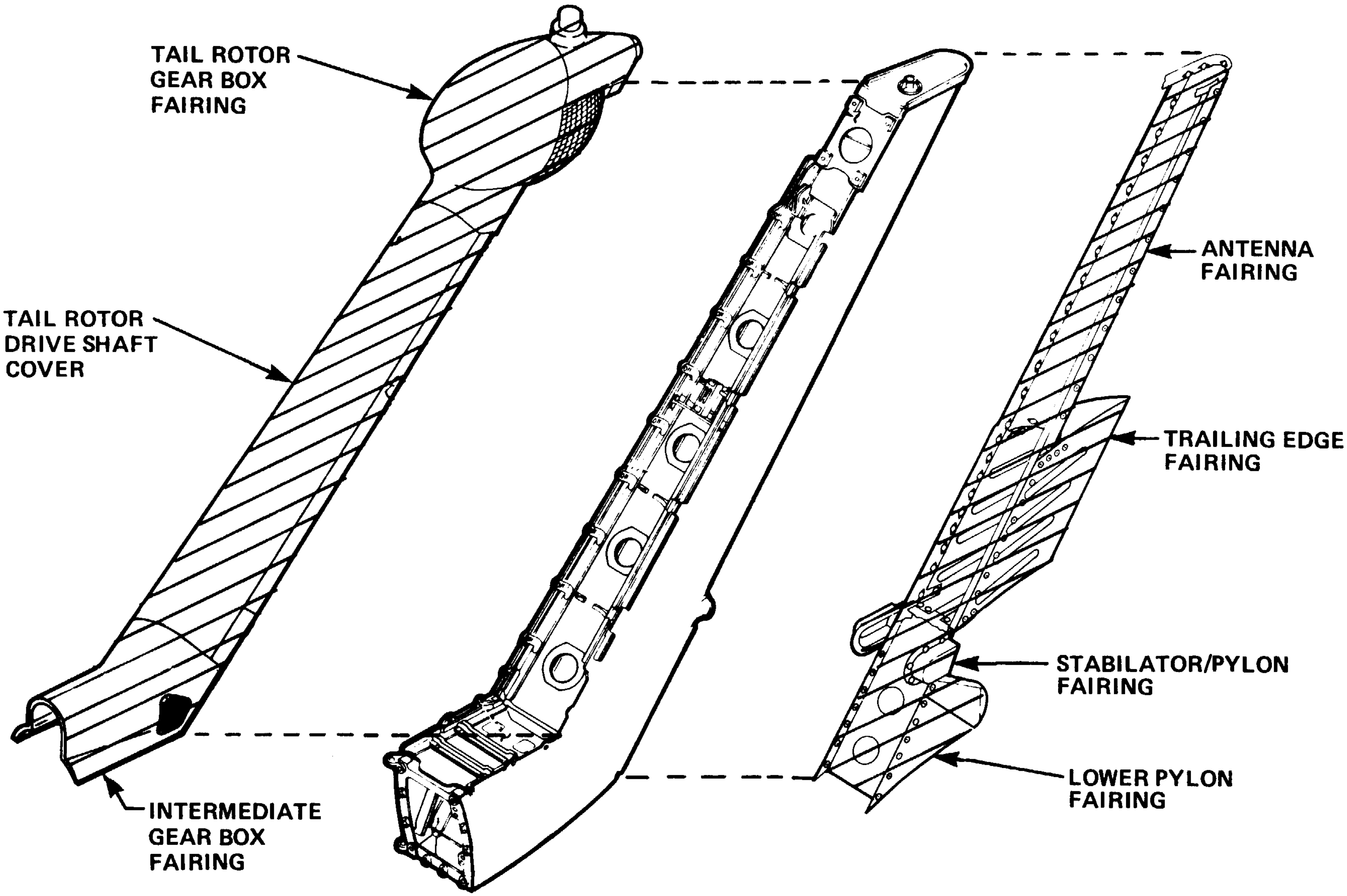
STATIC MODELING
Structure Not Modeled – Tail Rotor Pylon

Parts of the tail rotor pylon not modeled as structure include:

1) Intermediate Gearbox Fairing
2) Tail Rotor Drive Shaft Cover
3) Tail Rotor Gear Box Fairing
4) Lower Pylon Fairing
5) Stabilator/Pylon Fairings
6) Trailing Edge Fairing
7) Antenna Fairing

STATIC MODELING

Structure Not Modeled – Tail Rotor Pylon



STATIC MODELING
Structure Not Modeled - Stabilator

Parts of the stabilator not modeled as structure include:

1) Leading Edge Fairing*

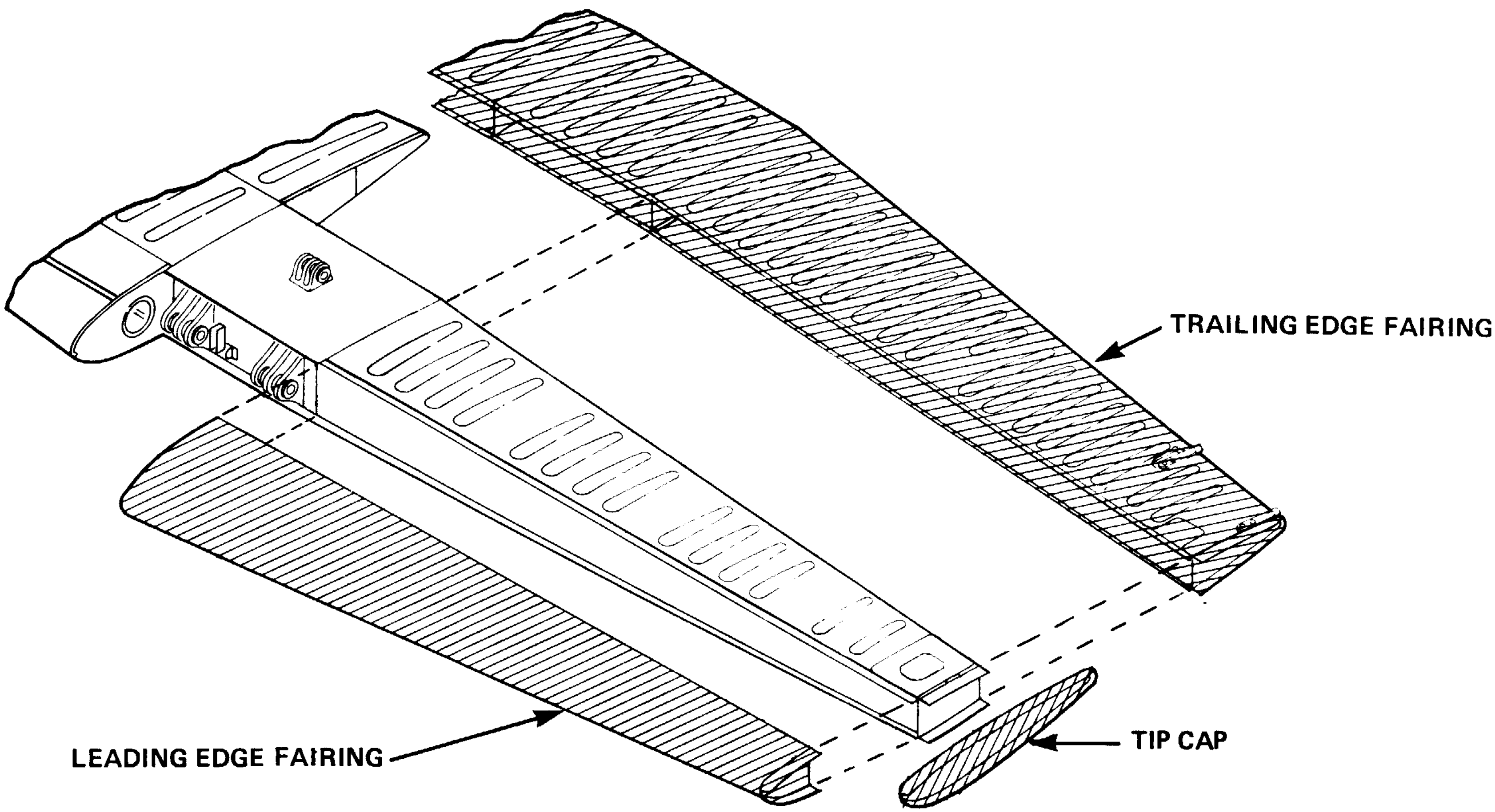
2) Tip Cap

3) Trailing Edge Fairing*

* *In reviewing the structure of the stabilator during the modeling process, the leading and trailing edge fairing were deemed to have sufficient stiffness as to have an effect on the vibration modes in which the stabilator participates and were therefore represented in the model.*

STATIC MODELING

Structure Not Modeled – Stabilator



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STATIC MODELING
Assumptions for Static Modeling

The accompanying figure shows the basic assumptions to be used in formulating the NASTRAN finite element model of the UH–60A. These assumptions are generally consistent with the structural behavior of an airframe built of semi–monocoque construction.

The stringers and longerons are assumed to have only the capability to carry axial loads. Secondary stresses are usually handled empirically for these members. The skins on the outer shell are generally thin and buckle at low loads, and are assumed to carry the flight loads in shear only.

Machined frames and buttline beams are represented with bar elements, while built–up frames and beams are represented in the model with ROD and SHEAR elements. These modeling assumptions are typically made to facilitate the sizing of the structure.

All frames and stringers are modeled separately, no lumping of adjacent structural members is performed. This approach to modeling the structure is followed to eliminate the cost of computing the section properties for the lumped elements, and the cost and inaccuracies of redistributing the computed loads for the lumped elements to the individual structural members.

STATIC MODELING

Assumptions for Static Modeling

1. Typical semi–monocoque construction
   a) Stringers and longerons (including effective skin) carry axial loads only
   b) Skins carry shear loads only.
2. Machined frames and buttline beams are modeled with BAR elements
3. Built–up frames and buttline beams are modeled with RODS and SHEAR panels
4. All frames are modeled separately, ie., no lumping.
5. All stiffeners are modeled separately, ie., no lumping.

STATIC MODELING GUIDES
Frames and Buttline Beams

The accompanying figure shows the cabin frame at STA 7.82 m (308 in.) and the corresponding finite element model. Built-up frames and buttline beams are normally modeled with ROD and SHEAR elements. Machined frames and buttline beams are generally modeled with BAR elements.* The following procedures are used in idealizing frames and buttline beams:

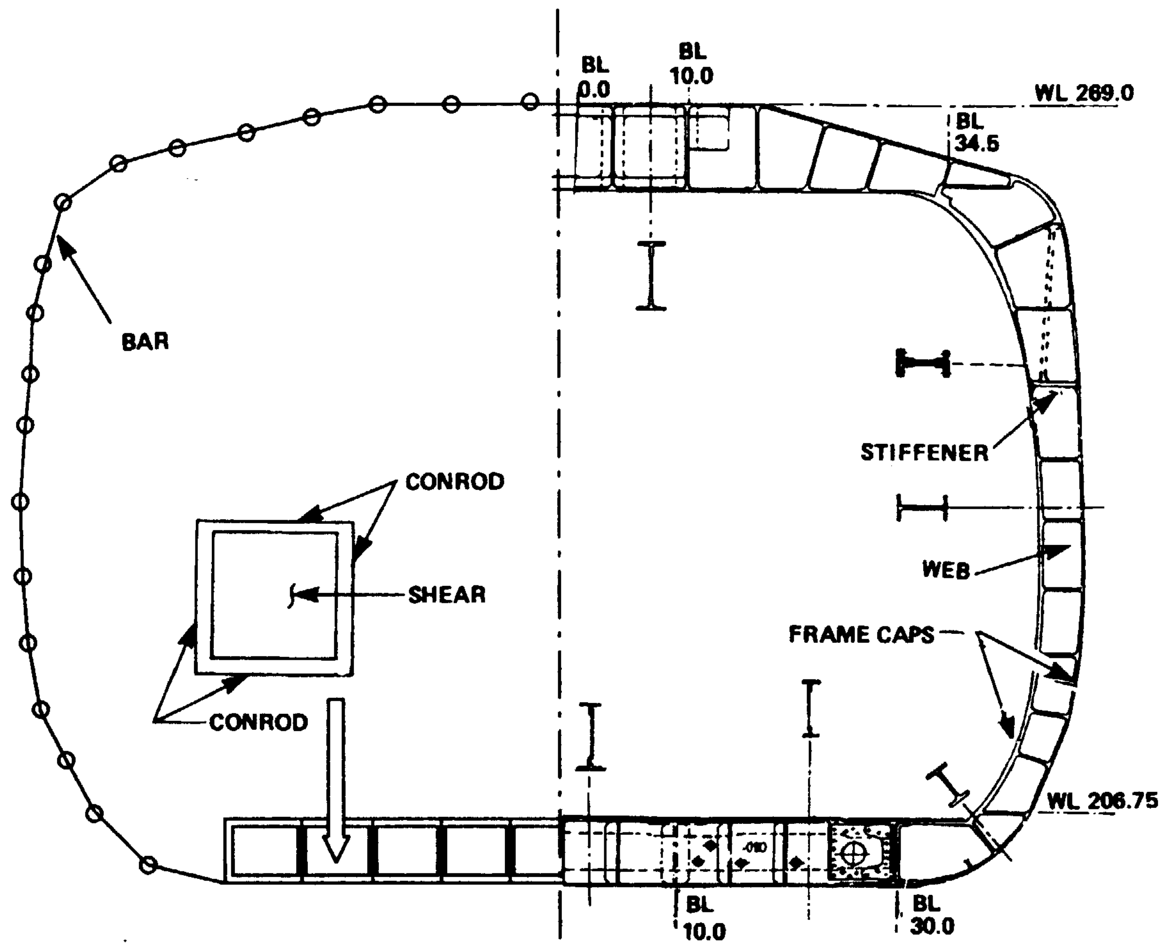
1) For ROD and SHEAR element idealizations:
   - a) The caps are assumed to carry axial load and are represented by CONROD elements.
   - b) The webs are assumed to carry shear loads only and are represented by SHEAR elements.
   - c) Generally, outer nodes are located at the outer skin line and the inner nodes are located at the inboard surface of the inboard cap. Areas are not adjusted to provide the proper bending inertia.
   - d) In computing the area of the caps effective skin from both the outer shell and web is normally included. However, for this study only the actual cap areas are used.
   - e) The area of any strap is lumped with the cap.
   - f) The average area is used for tapered caps.
   - g) Cap areas are reduced for fastener holes.
   - h) Web holes are ignored.

2) For BAR element idealizations:
   - a) Six degrees of freedom are specified for the BAR element.
   - b) Offsets are used to define the neutral axis.
   - c) Section properties are normally calculated using effective skin. However, for the purposes of this study effective skin is not used.

* *During the development of the model, it was decided that in order to properly represent the attachment of major structural members to each other, that all machined frames and buttline beams would be modeled using the procedures for built-up members.*

STATIC MODELING GUIDES

Frames and Buttline Beams



FRAME STA 308

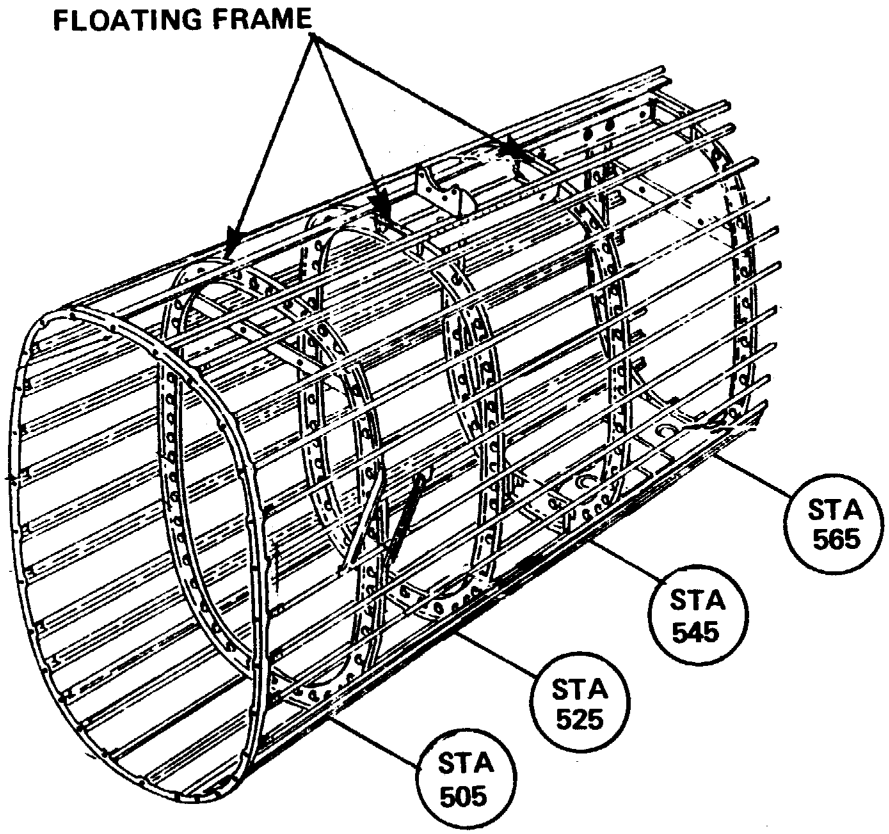
STATIC MODELING GUIDES
Floating Frames

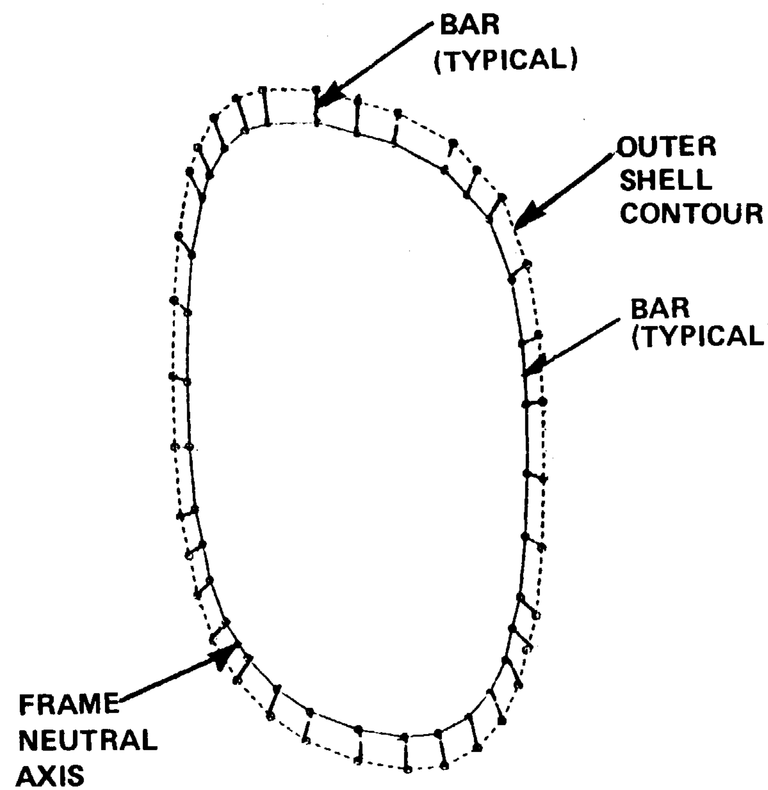
The second through fifth frames in the tailcone section shown below are of the floating type. In this type of construction the outboard cap of the frame is riveted to the inboard flanges of the stiffeners, so that the frame floats on the stiffeners. The primary function of the floating frames is to maintain the shape of the tailcone, and not to carry any significant flight loads. The flight loads are assumed to be carried by axial loads in the stringers and by shear in the outer skin panels.

The frame is to be modeled with BAR elements lying along the neutral axis of the frame. BAR elements will connect points on the frame with corresponding points on the outer shell to transfer any radial loads to the frame.

STATIC MODELING GUIDES

Floating Frames





NASTRAN REPRESENTATION
FRAME STA 505

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STATIC MODELING GUIDES
Skin And Stringers

Procedures used for modeling skins and stringers are:

1) Skins are modeled with SHEAR elements.*

2) Stringers are modeled with CONROD elements.**

3) Stringers are not lumped.

4) The area of skin from adjacent panels considered to be effective is lumped with the stringer. Procedures for calculating effective skin are presented in the next figure.

Longerons are usually modeled with CONROD elements if they carry axial loads only. When they carry both axial and transverse shear loads they are modeled with BAR elements.

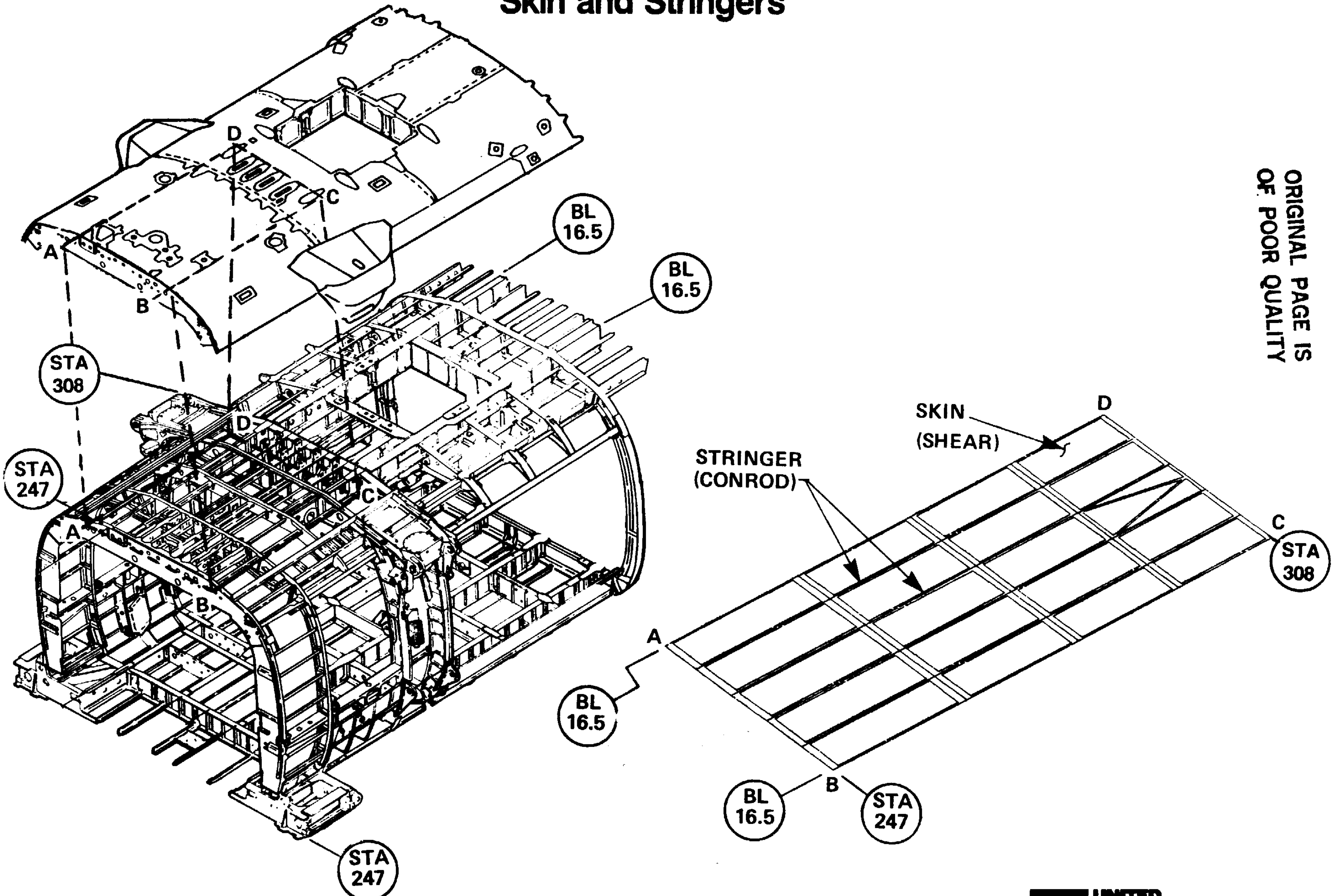
The accompanying figure illustrates the procedures used for modeling skins and stringers in the cabin roof between Stations 6.27 m (247 in.) and Station 7.82 m (308 in.).

* *In order to facilitate the development of the dynamics model, it was decided to model the skin using QUAD4 rather than SHEAR elements. In the statics model, the QUAD4"s would be assigned material properties associated only with shear stiffness.*

** *As part of an anticipated future effort to investigate the effects of secondary section properties on the dynamic response of the structure all CONROD elements were replaced by BAR elements.*

STATIC MODELING GUIDES

Skin and Stringers



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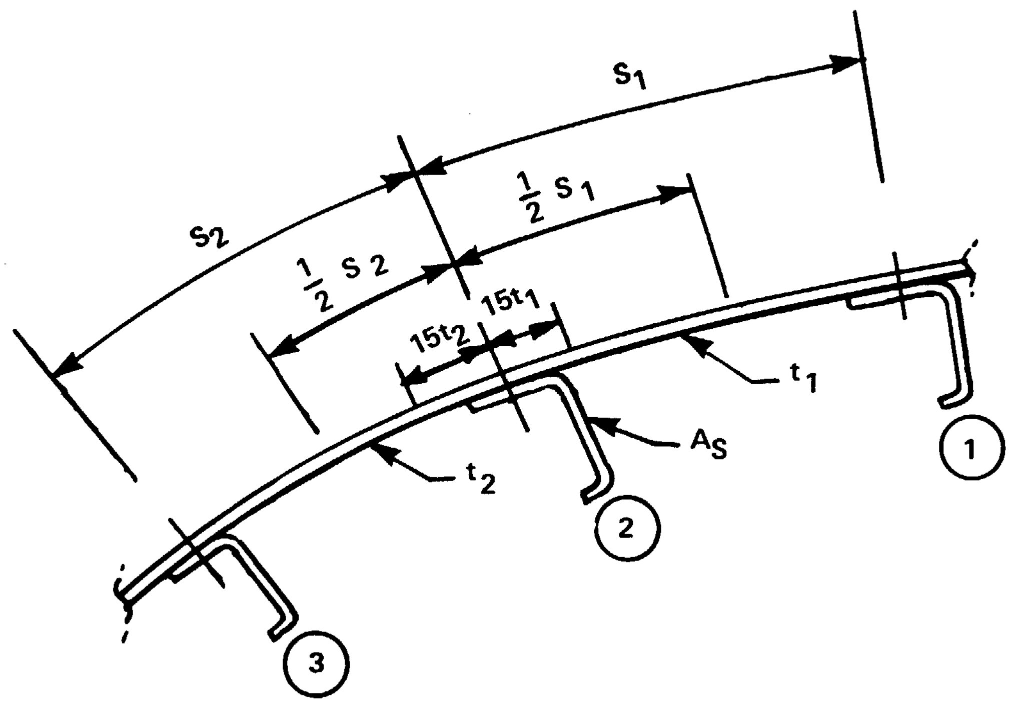
STATIC MODELING GUIDES
Effective Skin

The amount of effective skin lumped with the stringer area is dependent on whether the skin is in tension or compression. When the skin is in compression, the effective skin area is taken as fifteen times the thickness of the skin on each side of the rivet line. When the skin is in tension, the effective width of skin is taken as one-half the width of the panel times the thickness of the skin on each side of the rivet line.

For the current version of the Black Hawk model, four effective skin configurations have been defined. However, to simplify the changeover from the statics to the vibrations model, effective skin will not be lumped with the stringer areas in this study.

STATIC MODELING GUIDES

Effective Skin



CONSIDER STRINGER 2

TENSION: $A_{TEN} = \left(\frac{1}{2} S_2\right)\left(t_2\right) + \left(\frac{1}{2} S_1\right)\left(t_1\right) + A_S$

COMPRESSION: $A_{COMP} = 15t_1^2 + 15t_2^2 + A_S$

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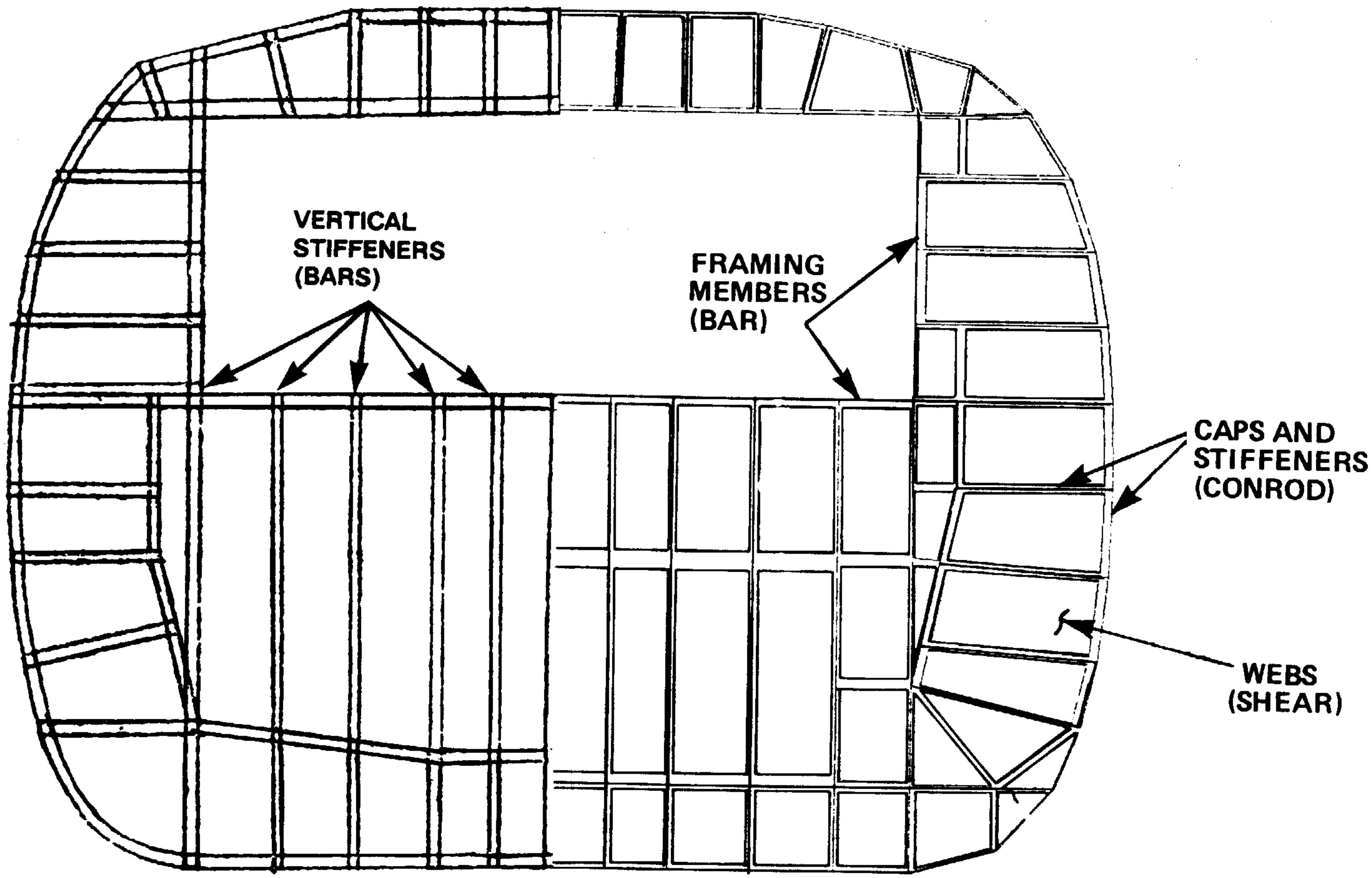
STATIC MODELING GUIDES
Bulkheads And Shear Webs

Bulkheads and shear webs are generally found in the cockpit, fuel cell bay and tail rotor pylon areas. For the most part these items are designed to react inplane loads and are idealized with CONROD elements for the stiffeners and SHEAR elements for the webs. However, some of the vertical stiffeners and framing members in the fuel cell bay bulkheads are also designed to carry transverse loads and are modeled with BAR elements. The accompanying figure illustrates these modeling procedures for the forward fuel cell bay bulkhead at Station 10.11 m (398 in.).

STATIC MODELING GUIDES
Bulkheads and Shear Webs



BULKHEAD
STA. 398

UNITED TECHNOLOGIES SIKORSKY AIRCRAFT

Cabin Floor

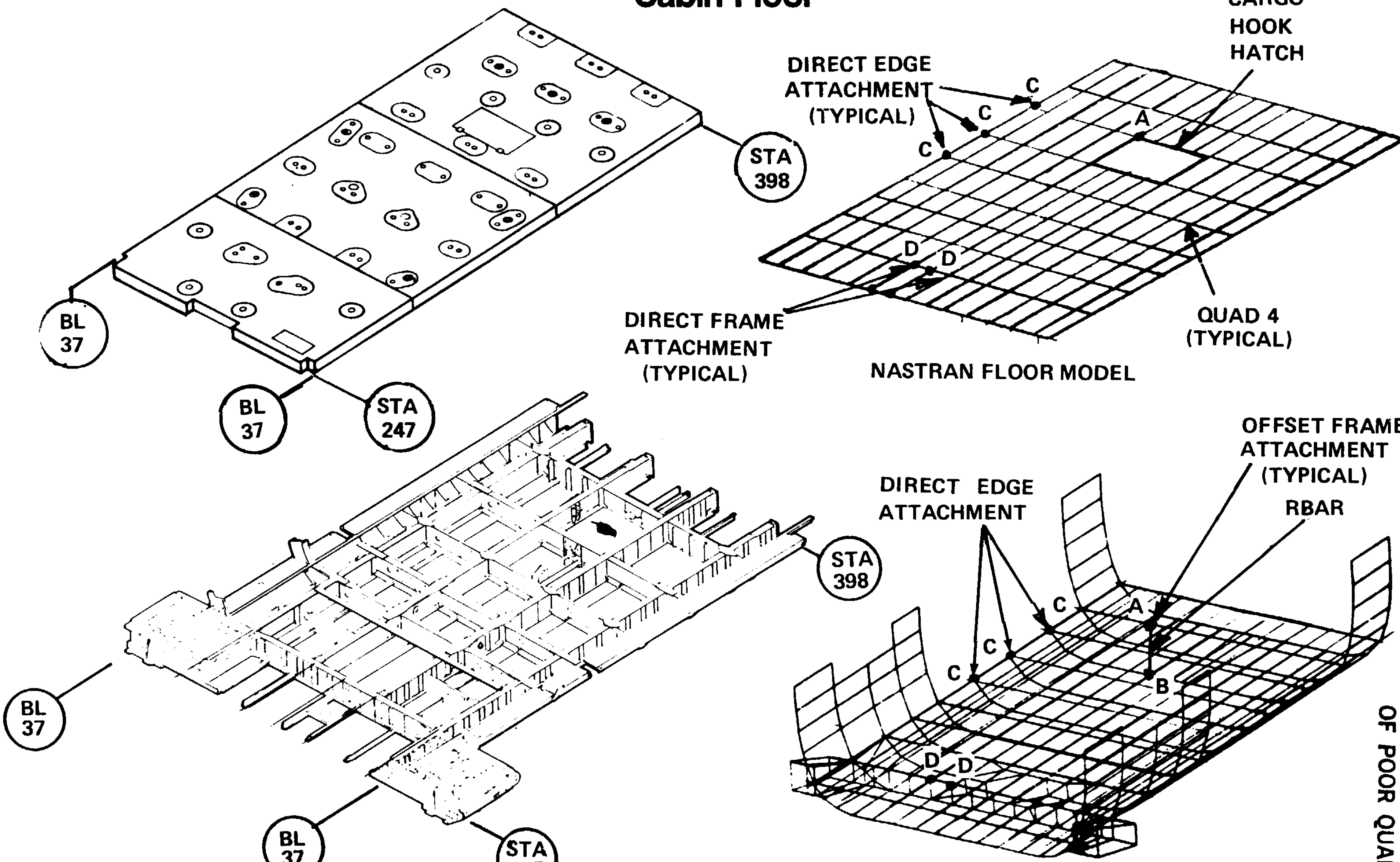
The cabin floor consists of three removable panels spanning the width of the cabin and running from Station 6.27 m (247 in.) to Station 10.11 m (398 in.). The floor is of honeycomb construction. It has 27 multipurpose fittings for cargo tiedown and troop seat and litter installations. The cargo hook is reached through a cargo hook access panel in the floor. The floor is attached to the airframe by bolts spaced approximately 0.076 m (3 in.) apart, running around the perimeter and along the beams and frames in the cabin floor. The floor is not isolated from the airframe.

The floor is modeled using QUAD4 elements. The mesh refinement used for the floor is identical to the projection onto the plane of the floor of the mesh used for the outer shell of the lower cabin. All grid point identification numbers used for the cabin floor will be unique with respect to those used in the airframe. The grid points in the floor model, which are coincident with those in the airframe model, will be connected to the airframe grid points by multipoint constraint relations (points C and D). The multipoint constraint relations, in this case, tie the three translational degrees of freedom of the floor model grid point to the same degrees of freedom for the corresponding grid point in the airframe model. In the cases where the frame and beams are represented in the airframe model by BAR elements, the grid points for the floor and airframe are connected by RBAR rigid elements (points A and B). The RBAR relates the three translational degrees of freedom of the floor model grid point (A) to all six degrees of freedom of the corresponding grid point (B) in the airframe model.*

* *As all frames and beams are to be modeled as built-up members the floor model is attached to the airframe model entirely by multi-point constraint relations, as defined above for points C and D.*

STATIC MODELING GUIDES

Cabin Floor



NASTRAN FLOOR MODEL

NASTRAN LOWER CABIN MODEL

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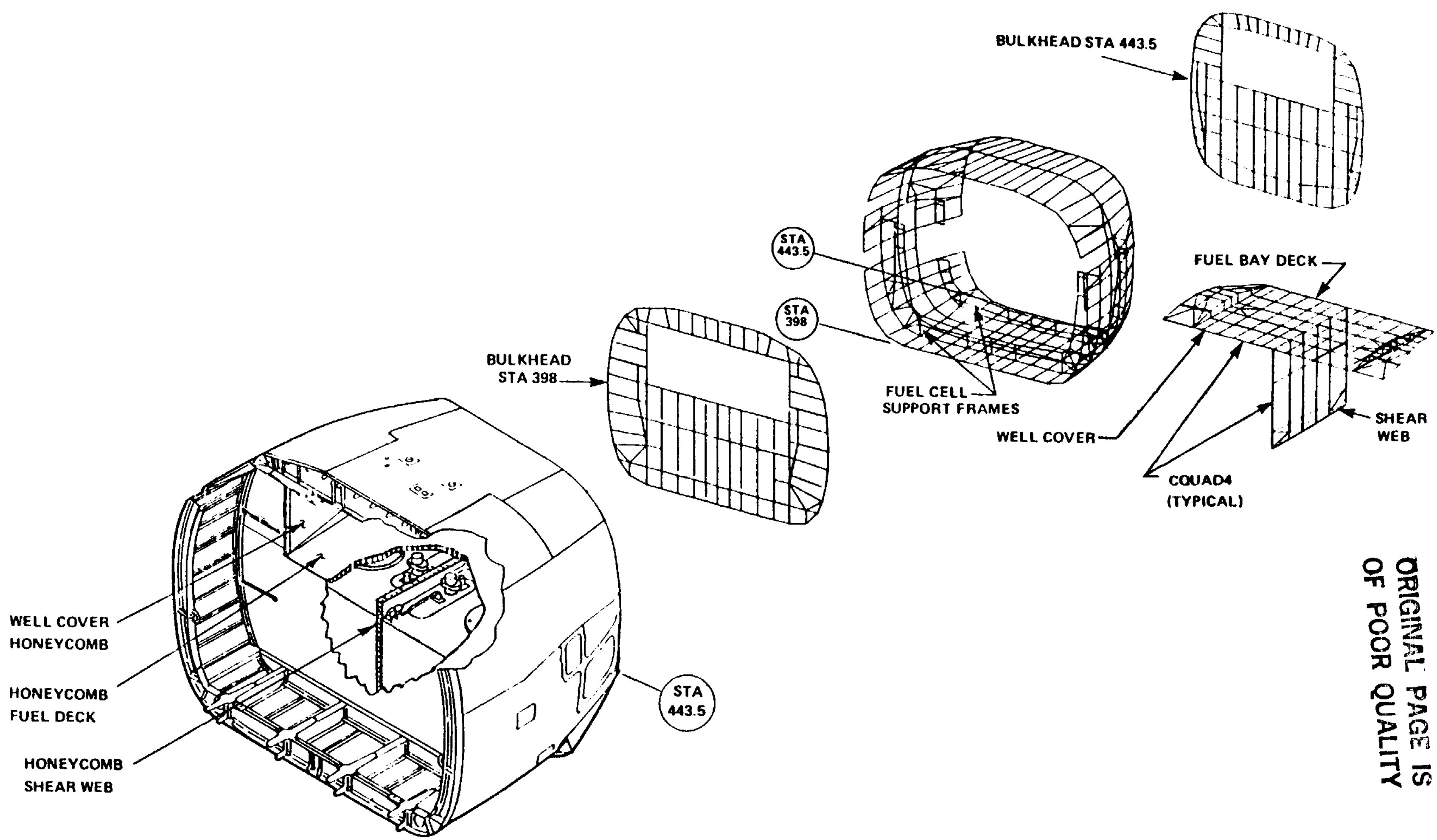
STATIC MODELING GUIDES
Fuel Bay

The accompanying figure illustrates the extent of the modeling of the fuel cell bay. The bulkheads at Stations 10.11 m (398 in.) and 11.26 m (443.5) are modeled using the guidelines indicated previously for bulkheads. The honeycomb fuel bay deck and shear web are represented by QUAD4 elements having both membrane and bending stiffness.

STATIC MODELING GUIDES

Fuel Bay



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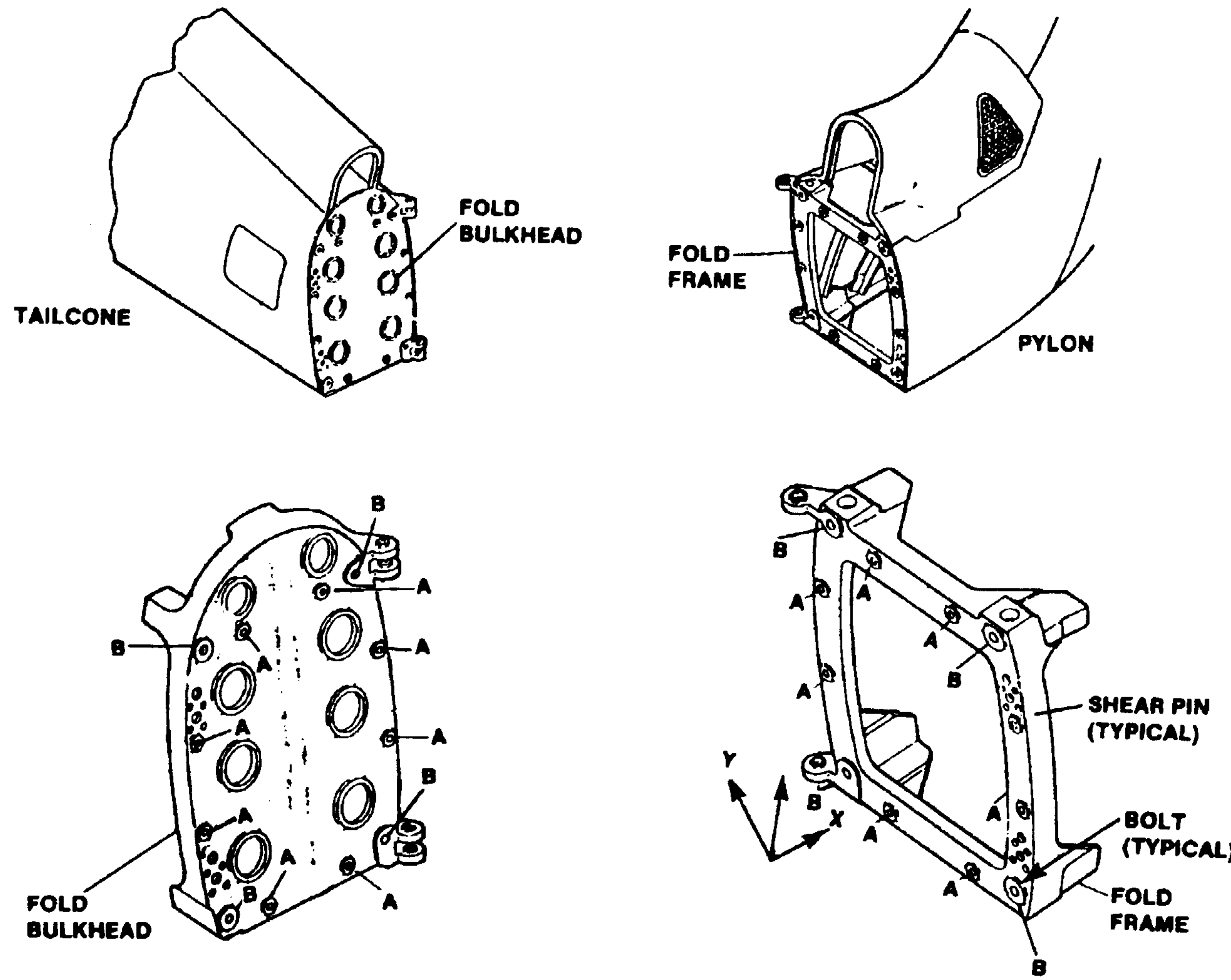
STATIC MODELING GUIDES
Tailcone/Pylon Attachments

The pylon fold area consists of a machined bulkhead attached to the tailcone and a machined frame attached to the tail rotor pylon. In flight, the two structural members are connected by a bolt at each corner (points B) and two shear pins on each of the four sides of the frame (points A). The fold area is designed so that both tensile and compressive loads are transferred at the bolt points, while shear loads in the plane of the bulkhead are transferred through the shear pins. No loads are assumed to be carried by the two hinges.

The fold bulkhead is represented by QUAD4 and TRIA3 elements with membrane properties. The fold frame is represented by BAR elements with 6 degrees of freedom per grid point. Multipoint constraint relations are used to tie the two sections of the model together to represent the load transfer mechanisms.

STATIC MODELING GUIDES

Tailcone/Pylon Attachments



UNITED TECHNOLOGIES SIKORSKY AIRCRAFT

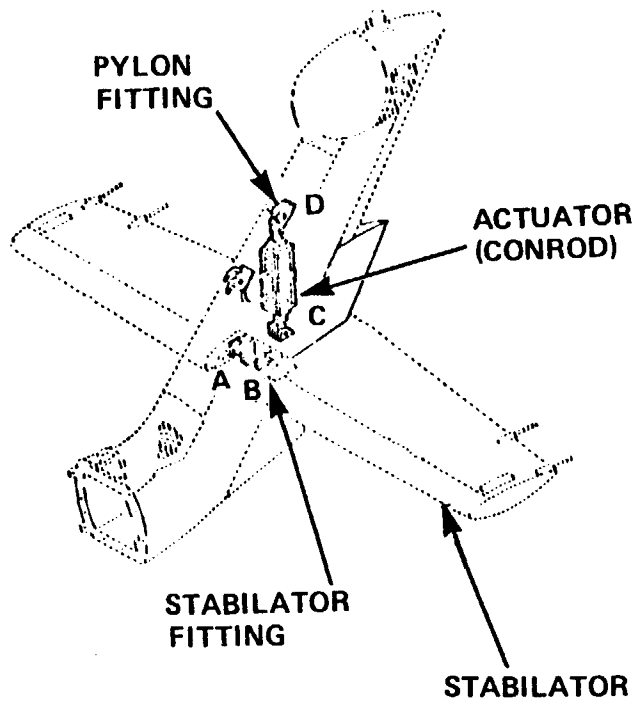
STATIC MODELING GUIDES
Stabilator Attachments

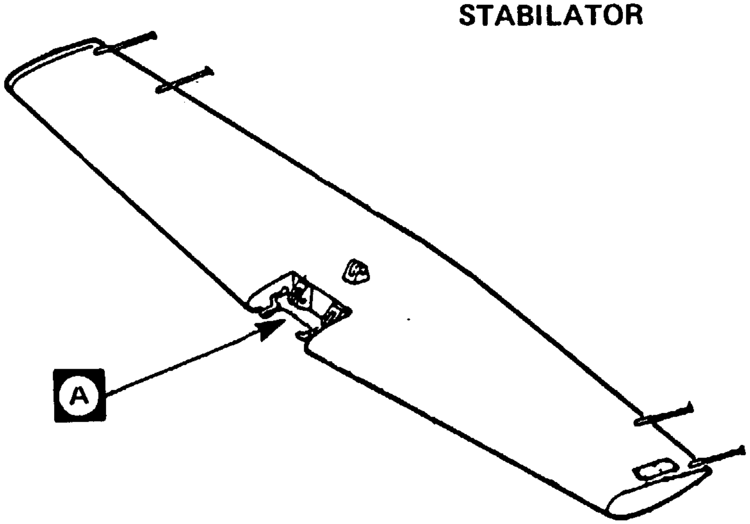
The stabilator is attached to the rear spar caps of the tail rotor pylon by double lugs at points A and B. The angle of attack of the stabilator is controlled by means of a hydraulic actuator. The actuator is attached to the upper surface of the stabilator by a lug at point C, and to the forward spar of the pylon by a machined fitting at point D.

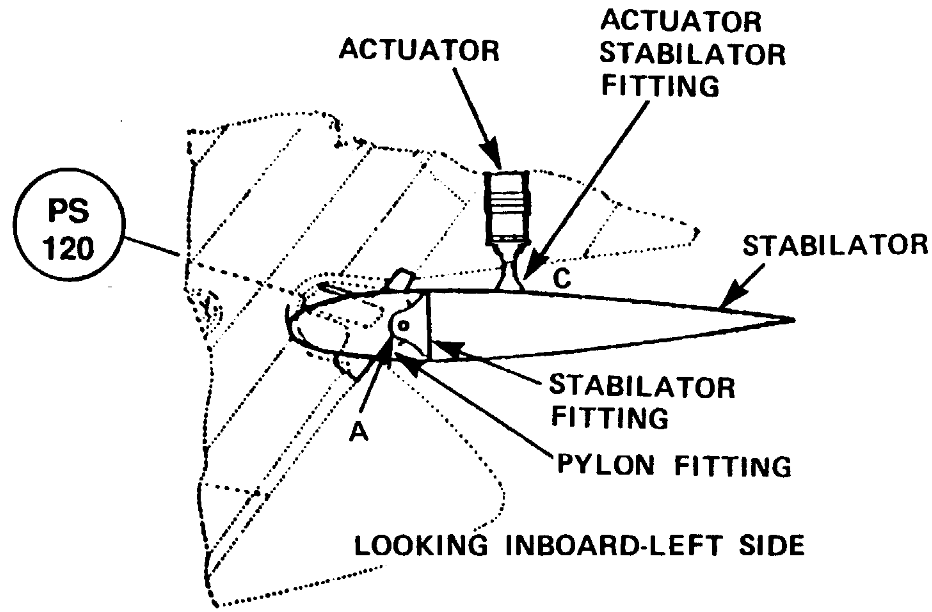
In the NASTRAN model the actuator is represented by a CONROD element. The lugs of the fitting are represented by TRIA3 elements with membrane and bending properties. The TRIA3 elements are attached directly to the grid points at the intersection of the pylon stabilator rib at Pylon Station 3.05 m (120 in.) and the rear spar.

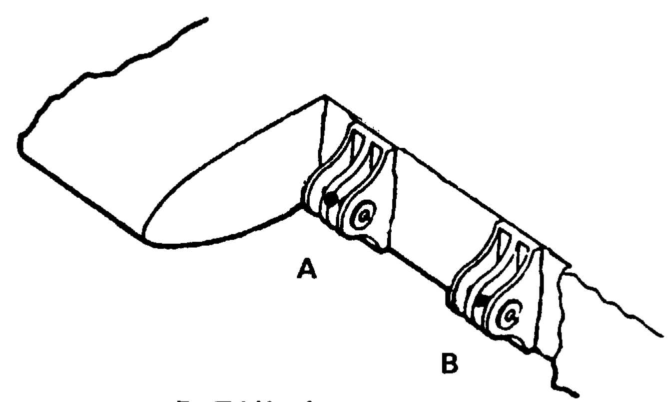
STATIC MODELING GUIDES

Stabilator Attachments









DETAIL A

UNITED TECHNOLOGIES SIKORSKY AIRCRAFT

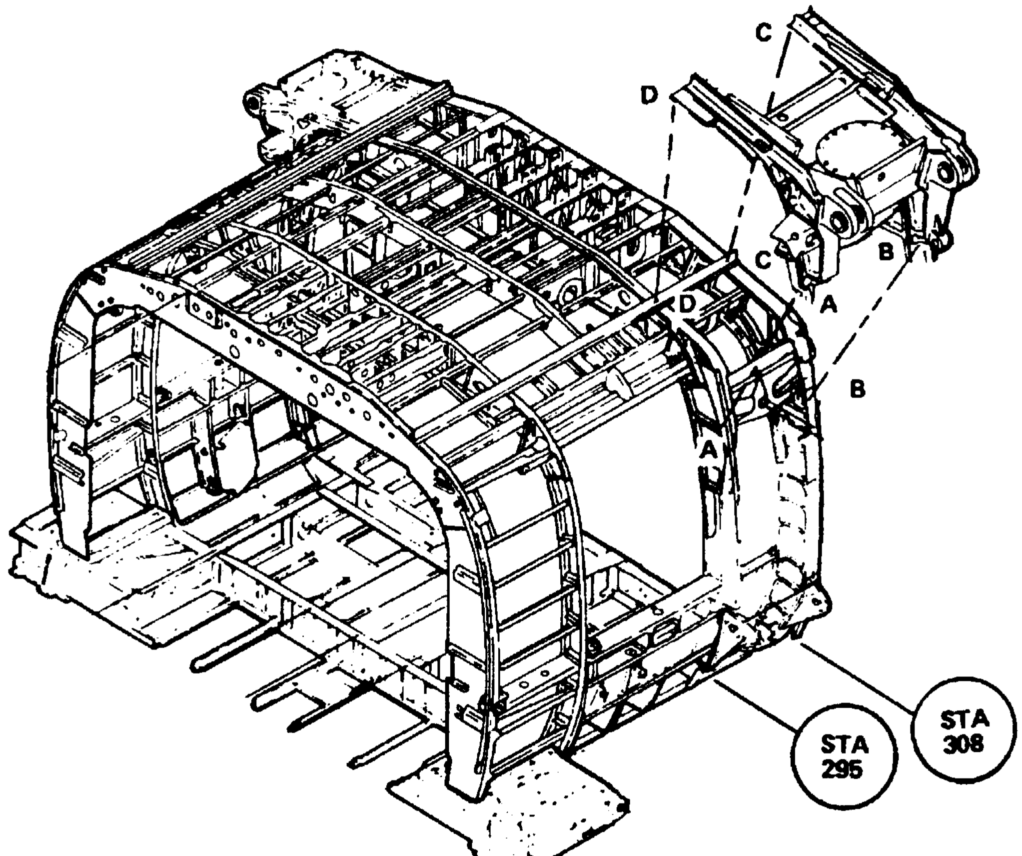
STATIC MODELING GUIDES
ESSS Upper Fitting

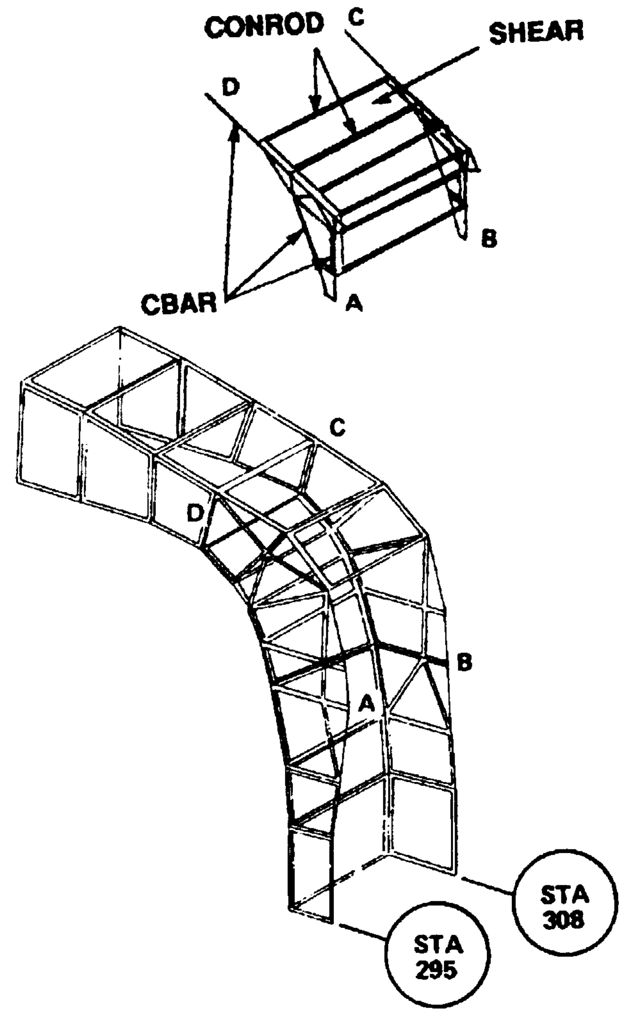
The External Stores Support System (ESSS) consists of a graphite epoxy boxed I–Beam (not shown) extending outboard from the bay between Stations 7.49 m (295 in.) and 7.82 m (308 in.). The boxed I–Beam is supported at the root end by the ESSS upper fitting which is tied to the top of the two frames, and by four support struts which are connected to the lower sides of these frames by lugs.

The ESSS upper fitting is represented in the NASTRAN model by ROD and SHEAR elements for the longitudinal webs, and by BAR elements to represent the edge members in the two station planes. The upper fitting is continuously attached to the forward frame between points A and D and to the aft frame between points B and C. The lower lug fittings are represented in the model by TRIA3 elements with membrane and bending stiffness.

STATIC MODELING GUIDES

ESSS Upper Fitting





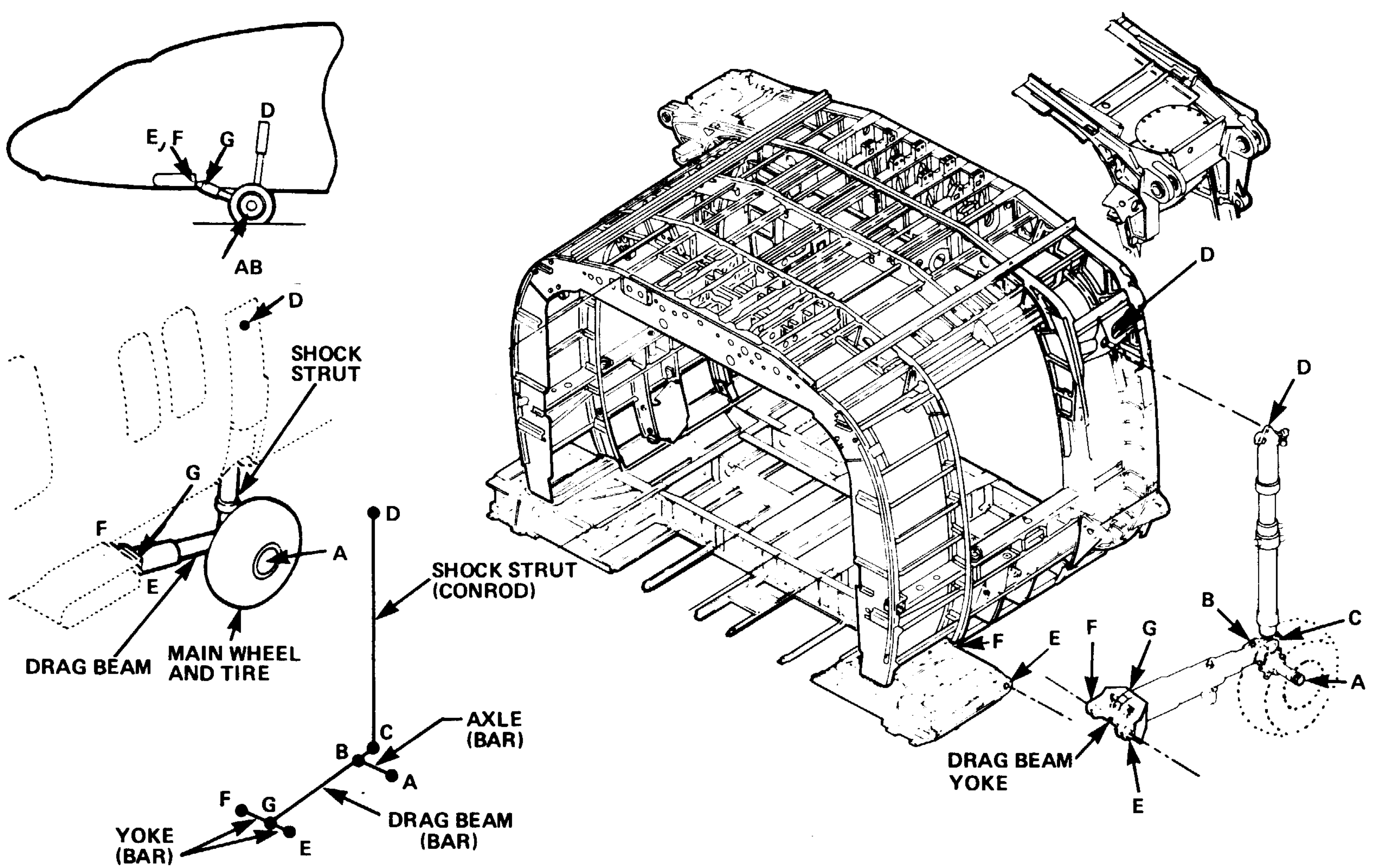
UNITED TECHNOLOGIES SIKORSKY AIRCRAFT

STATIC MODELING GUIDES
Main Landing Gears

The accompanying figure illustrates the modeling of the main landing gears. The shock strut is represented by a CONROD element. All other components of the landing gear are represented by BAR elements with axial and bending stiffness.

STATIC MODELING GUIDES

Main Landing Gears



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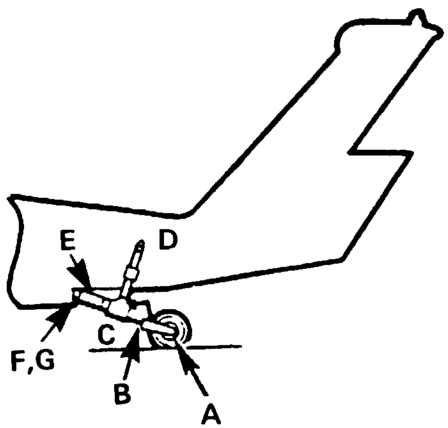
UNITED TECHNOLOGIES SIKORSKY AIRCRAFT

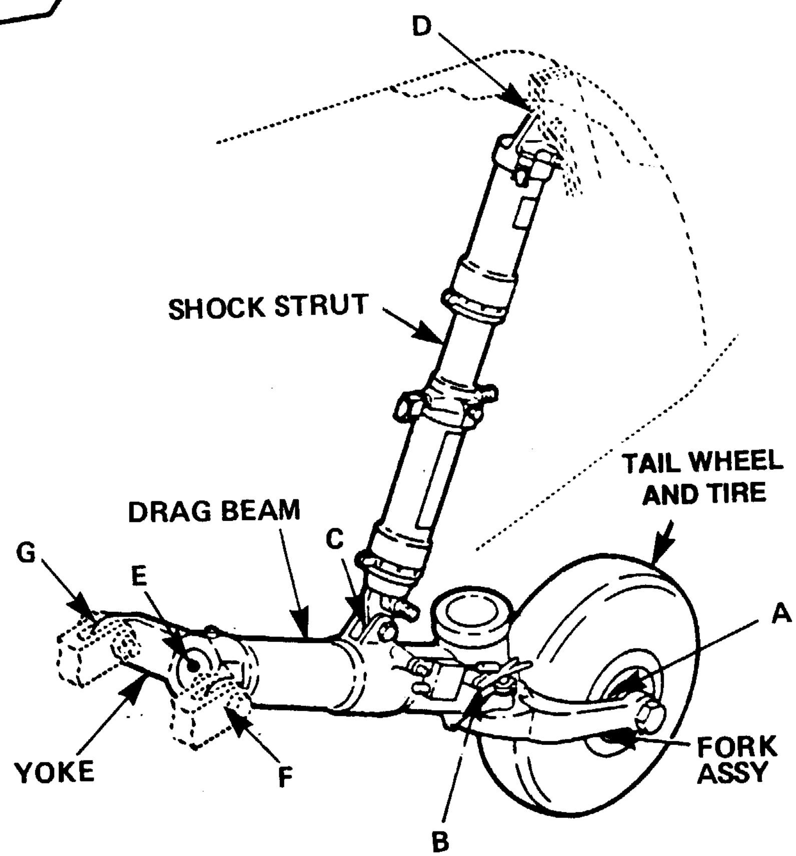
STATIC MODELING GUIDES
Tail Landing Gear

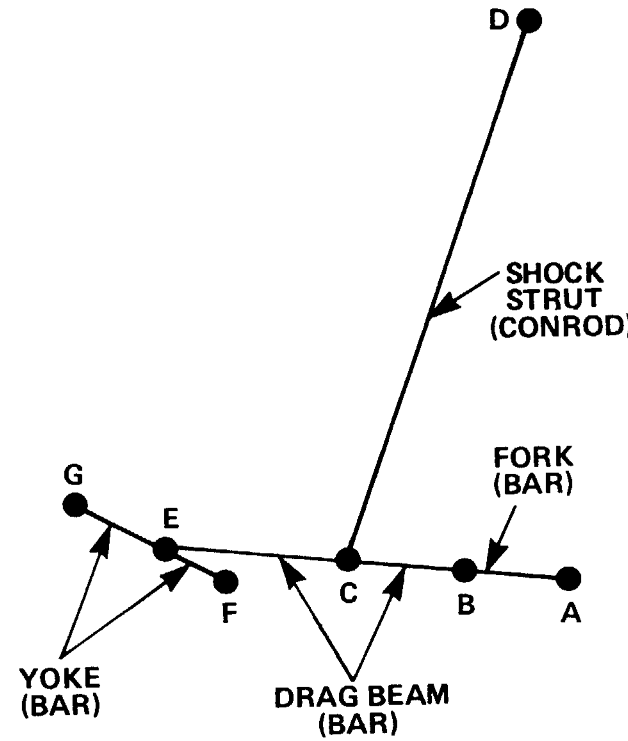
The accompanying figure illustrates the modeling of the tail landing gear. The shock strut is represented by a CONROD element. All other components are represented by BAR elements with axial and bending stiffness.

STATIC MODELING GUIDES

Tail Landing Gear







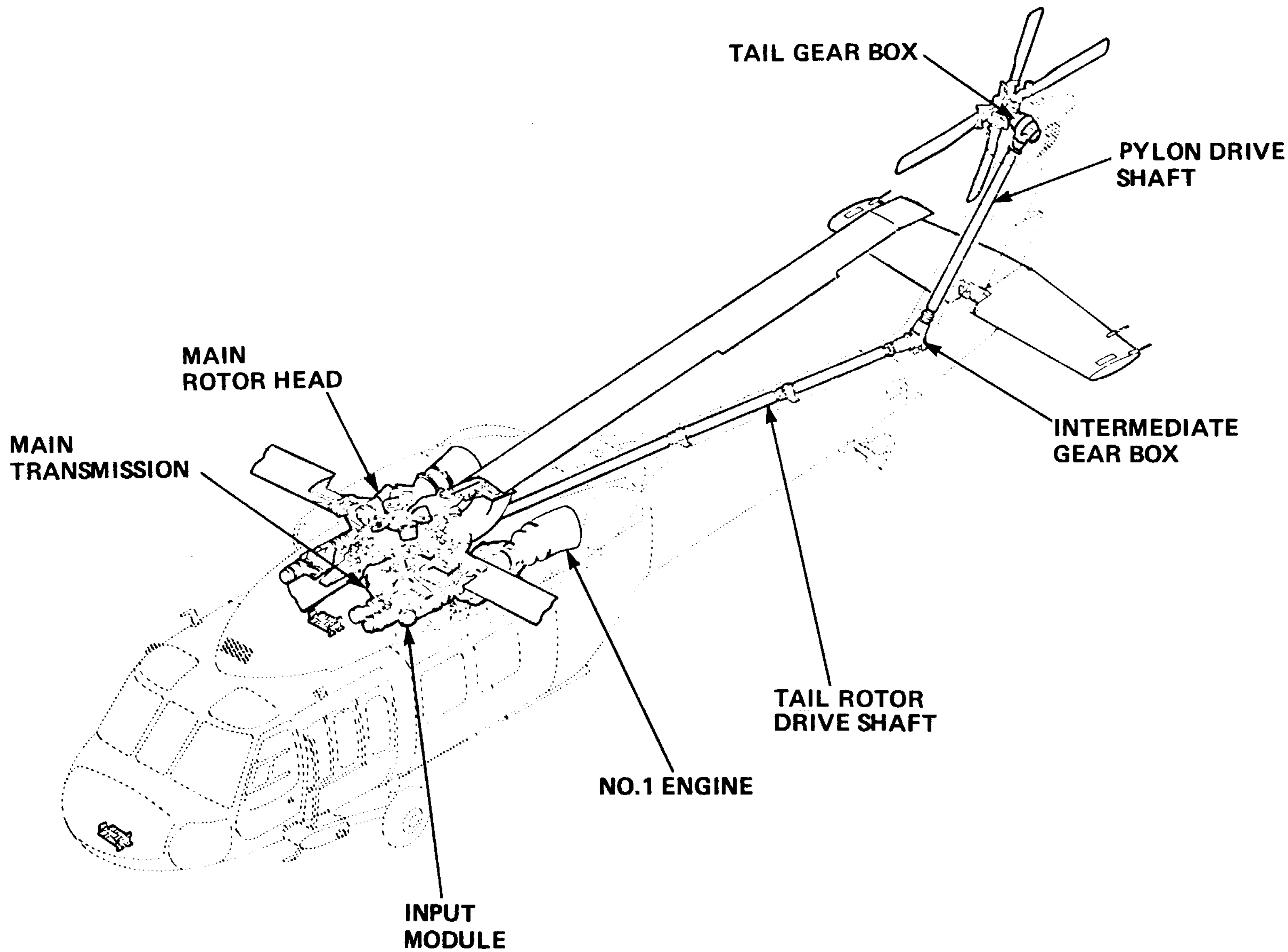
UNITED TECHNOLOGIES SIKORSKY AIRCRAFT

STATIC MODELING GUIDES
Power and Drive Train Systems

This figure shows the major components of the power and drive train systems for the UH-60A. The modeling procedures to be used for representing these components in the NASTRAN model are illustrated in subsequent figures.

STATIC MODELING GUIDES

Power and Drive Train Systems



UNITED TECHNOLOGIES SIKORSKY AIRCRAFT

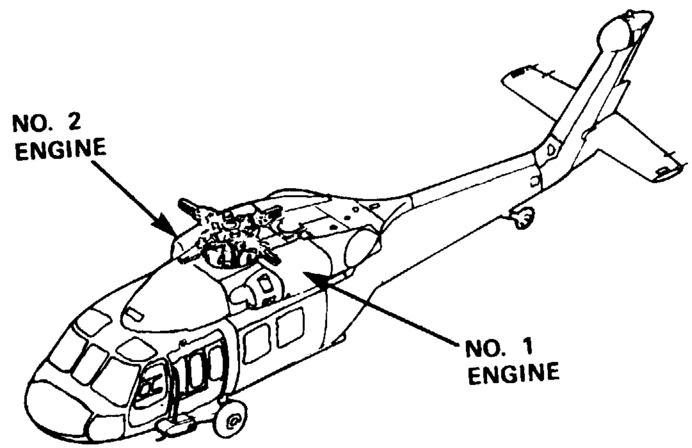
STATIC MODELING GUIDES
Engine and Engine Fittings

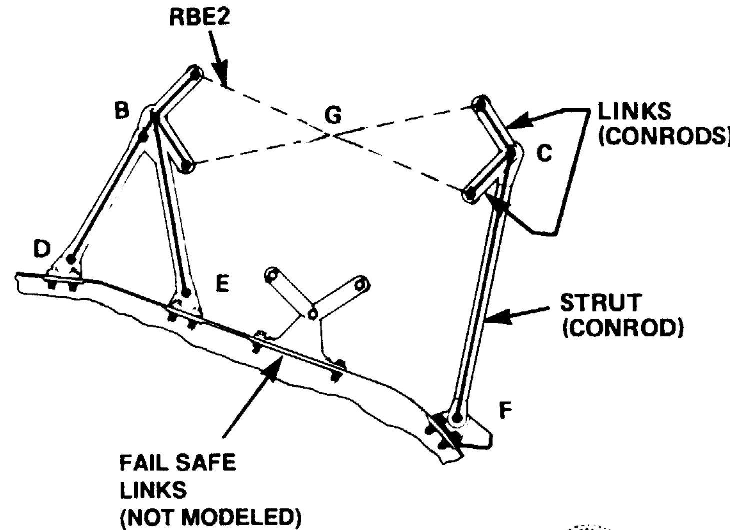
This figure shows the support system for the engines. The aft end of each engine is supported at Station 9.63m (379 in.) by links and struts which distribute the vertical and side loads from the engine to the airframe. Forward support for the engines is provided by the input modules to the main transmission. This support is capable of transferring the engine loads and moments about all three axes.

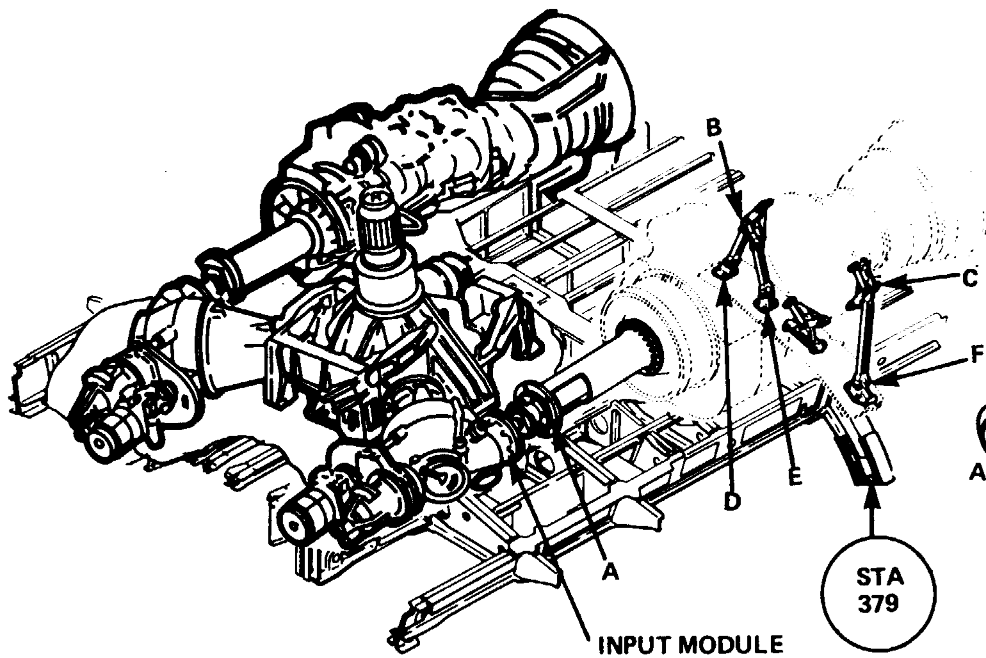
The aft links and struts are modeled by CONROD elements. The fail-safe links do not load up in normal flight and are not modeled. Each engine is represented by two RBAR rigid elements, joined together at the engine C.G. The forward end of the first RBAR is connected at point A to the NASTRAN model of the input module by means of an RBE2 rigid element. The aft end of the second RBAR is connected at point G to a RBE2 rigid element lying in the plane of the rings and struts (Station 9.63m (379 in.)).

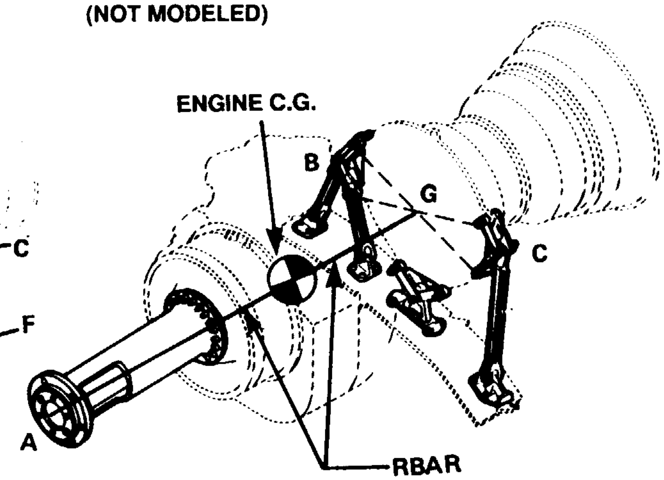
STATIC MODELING GUIDES

Engine and Engine Fittings









UNITED TECHNOLOGIES SIKORSKY AIRCRAFT

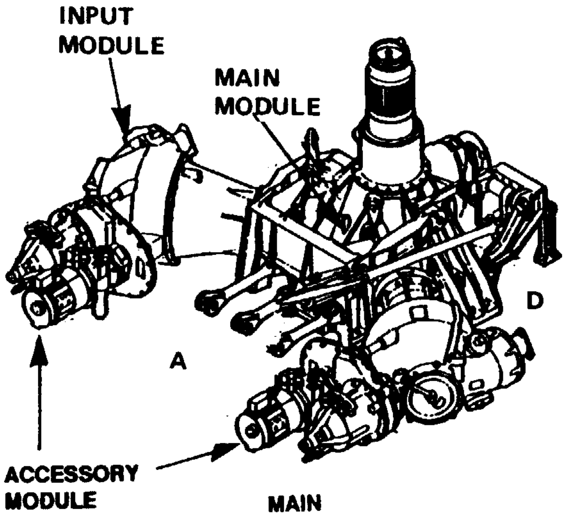
STATIC MODELING GUIDES
Main Transmission Assembly

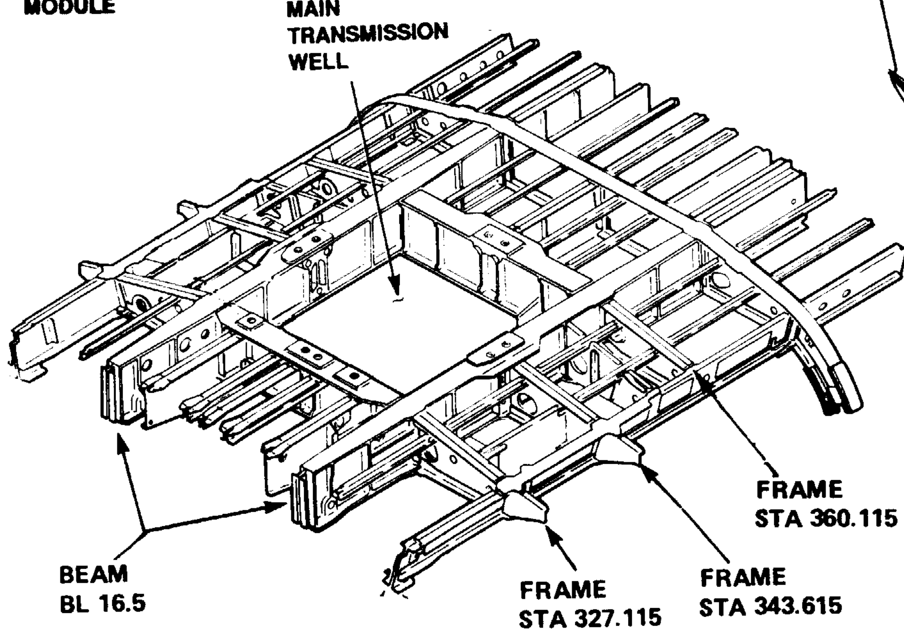
The main transmission assembly is mounted on the main fuselage with a built-in 3° forward tilt. It consists of 5 modules; the main transmission module, two input modules, and two accessory modules.

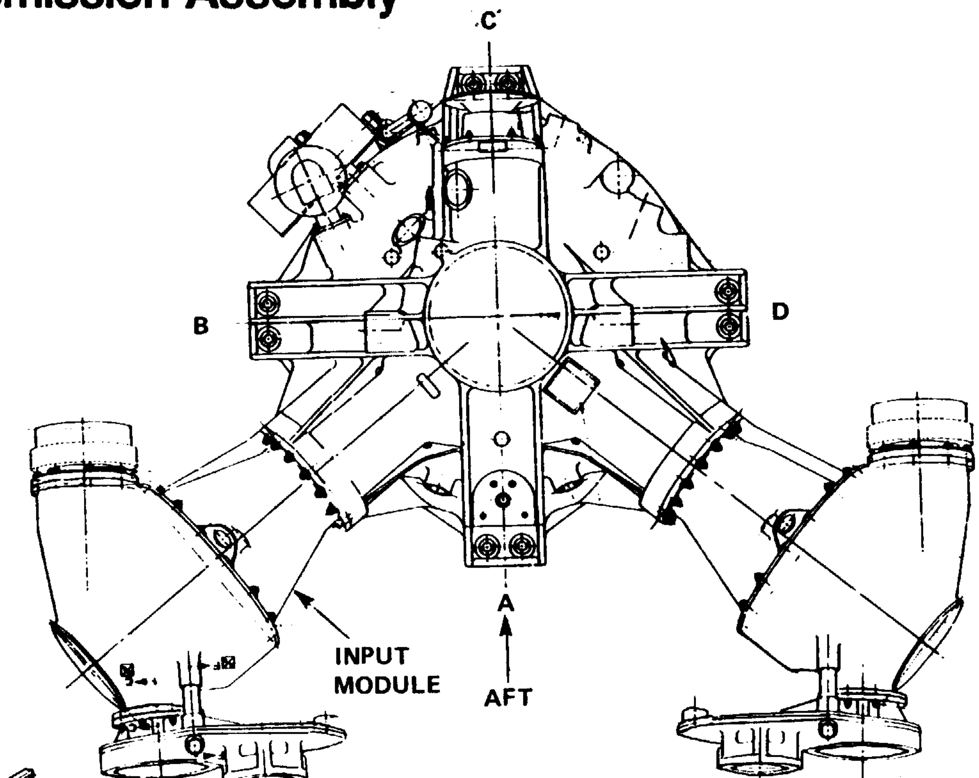
The main transmission is hard mounted to the frames at Stations 8.31m (327.115 in.) and 9.156m (360.115 in.) and the two beams at buttlines ± 0.42 m (16.5 in.). The two input modules are mounted on the left and right sides of the main transmission module. Beside transferring power from the engines to the transmission, they also provide forward support for the engines. The accessory modules are located on the front of the input modules. These modules drive the electrical generators and hydraulic pumps.

STATIC MODELING GUIDES

Main Transmission Assembly





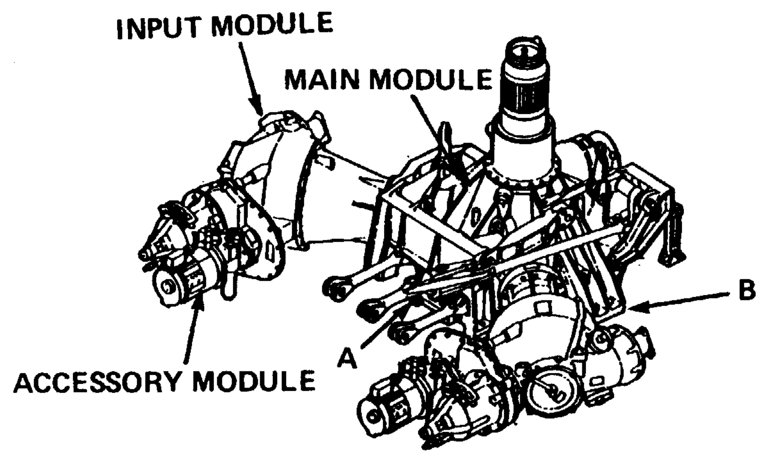


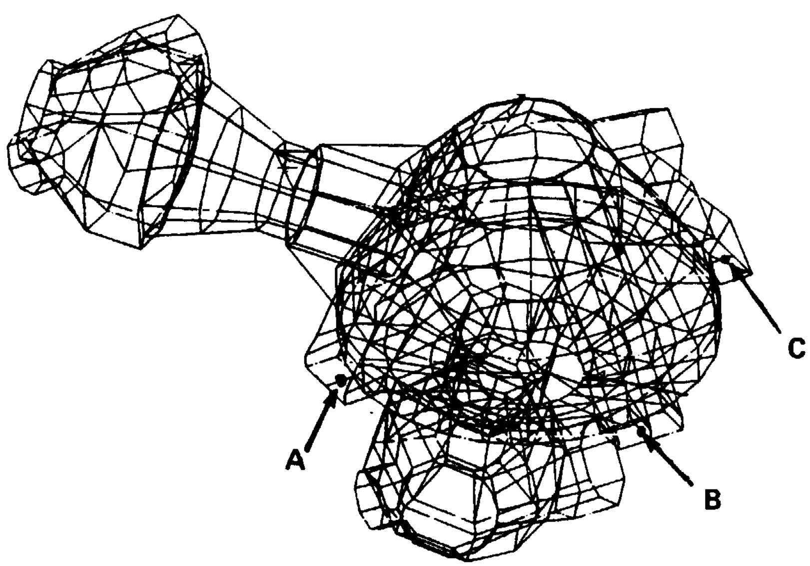
VIEW LOOKING DOWN

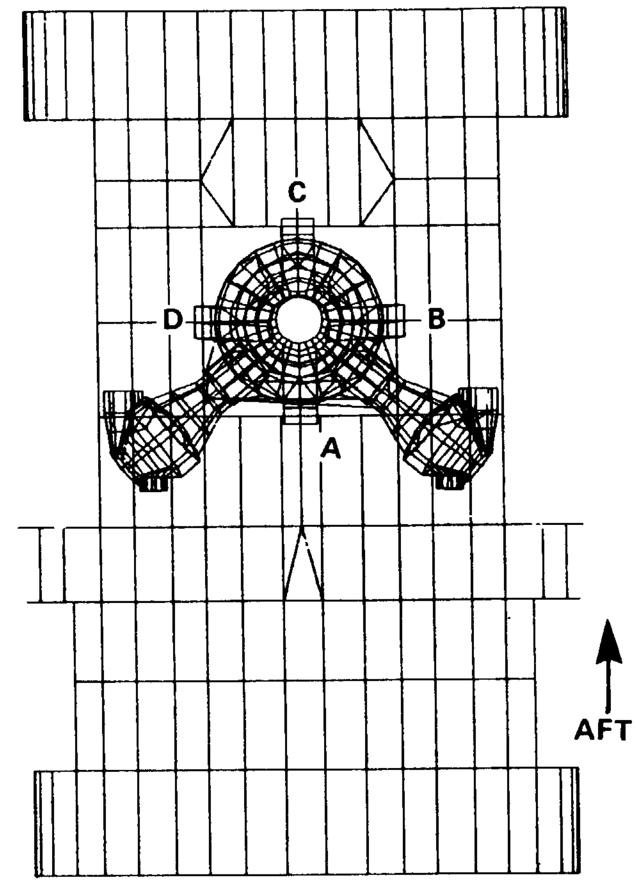
STATIC MODELING GUIDES
Main Transmission Assembly

The accompanying figure shows the finite element models for the housings of the main transmission and input modules. The housings are modeled with QUAD4 and TRIA3 element having membrane and bending stiffness. The grid points on the feet of the housing ribs are tied to pickup points on the airframe with multipoint constraint relations.

STATIC MODELING GUIDES
Main Transmission Assembly







CABIN ROOF STRUCTURE
VIEW LOOKING DOWN

STATIC MODELING GUIDES
Main Rotor Shaft

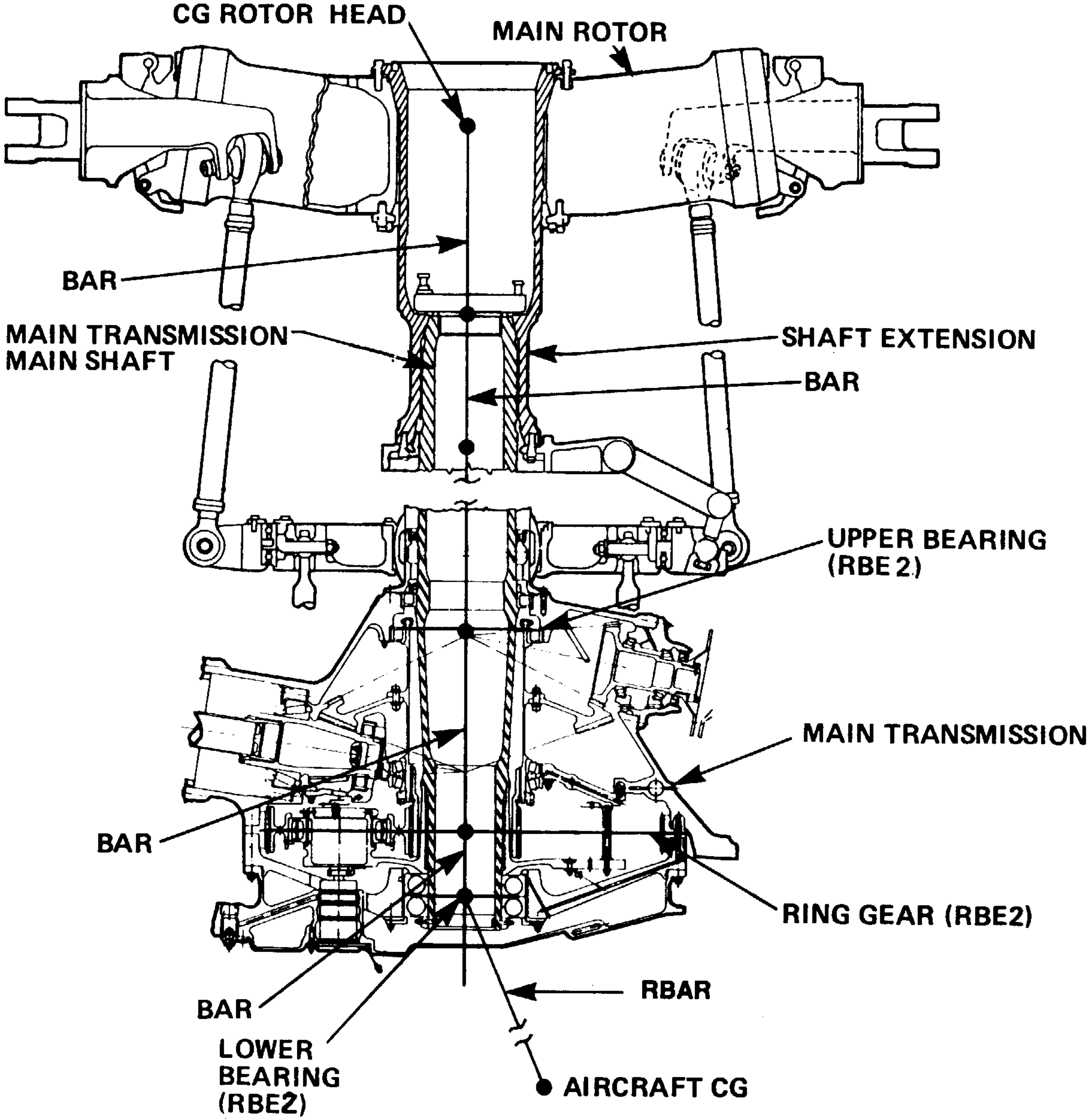
This figure illustrates the modeling of the main rotor shaft as well as the mechanism for supporting the model for static analysis with inertia relief.

The main rotor shaft is of two piece construction, consisting of the main shaft of the main transmission and the rotor head shaft extension. The rotor shaft is modeled as a series of BAR elements. Equivalent axial and bending stiffnesses are obtained for each BAR element by integrating the section properties of the shaft over the length of the segment. The shaft is connected to the transmission housing by three RBE2 rigid elements, which represent the upper and lower bearings and ring gears. The grid points on the perimeter of the RBE2 for the lower bearing are connected to the corresponding points on the housing to allow only radial and vertical load transfer. The grid points for the RBE2 for the upper bearing are tied to those on the housing to permit only radial load transfer, while those for the RBE2 element for the ring gear permit only tangential load transfer.

The centroidal point on the RBE2 for the lower bearing is connected to a grid point located at the C.G. of the aircraft by a RBAR element. The grid point at the C.G. is used as the "SUPPORT" point for static analysis with inertia relief.

STATIC MODELING GUIDES

Main Rotor Shaft



EQUIVALENT ROTOR SHAFT STIFFNESS

$$I_r = \frac{L}{\int \frac{d\ell}{I(\ell)}} \qquad \text{(BENDING)}$$

$$A = \frac{L}{\int \frac{d\ell}{A(\ell)}} \qquad \text{(AXIAL)}$$

WHERE:

$$A(\ell) = \frac{\pi}{4}\left(D_o^2 - D_i^2\right)$$

$$I(\ell) = \frac{\pi}{64}\left(D_o^4 - D_i^4\right)$$

D_o = OUTSIDE DIAMETER

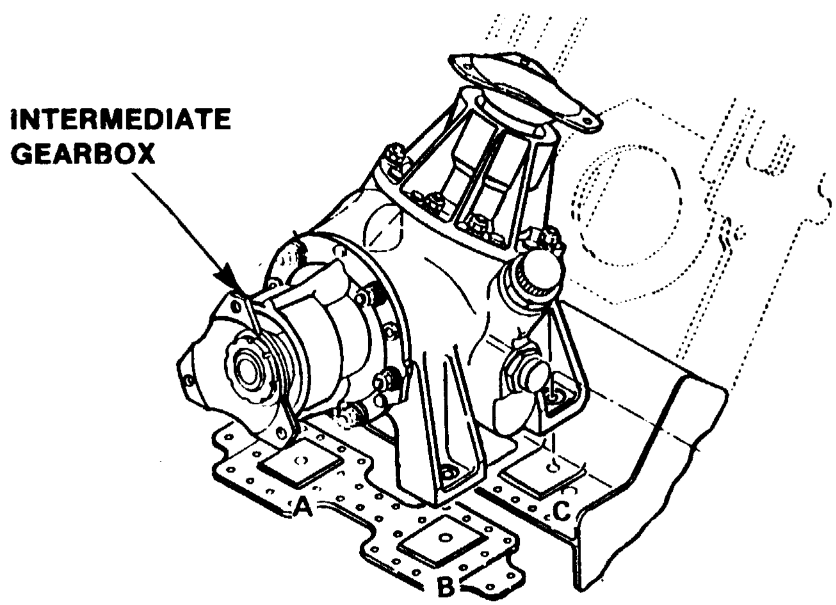
D_i = INSIDE DIAMETER

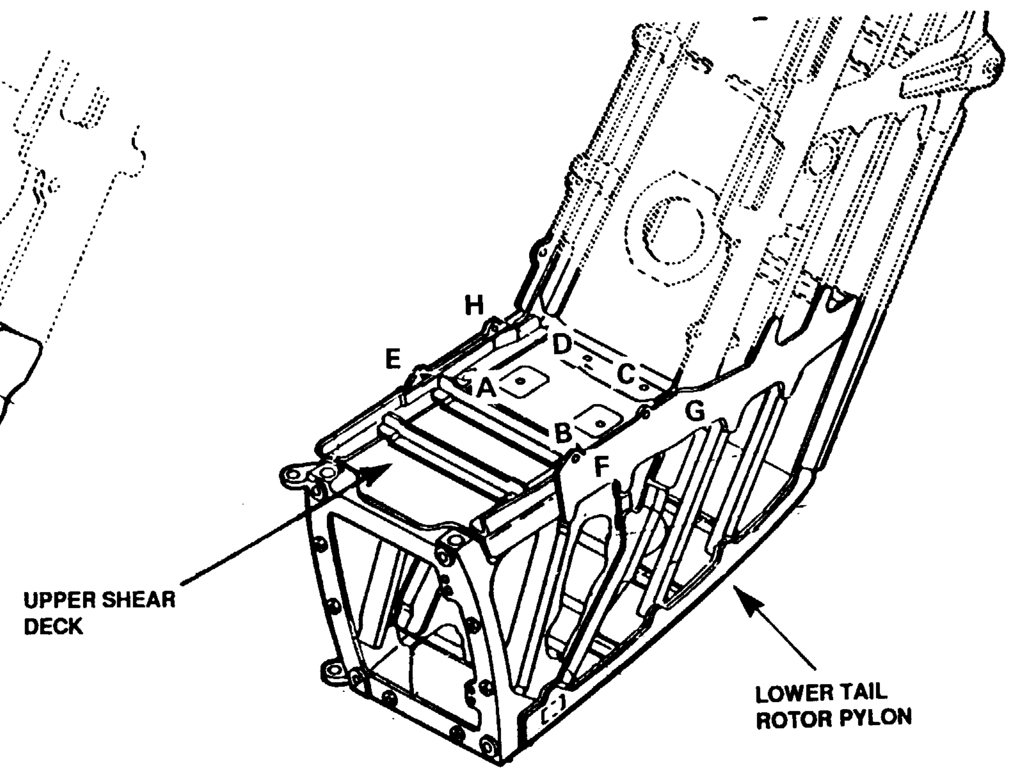
STATIC MODELING GUIDES
Intermediate Gearbox

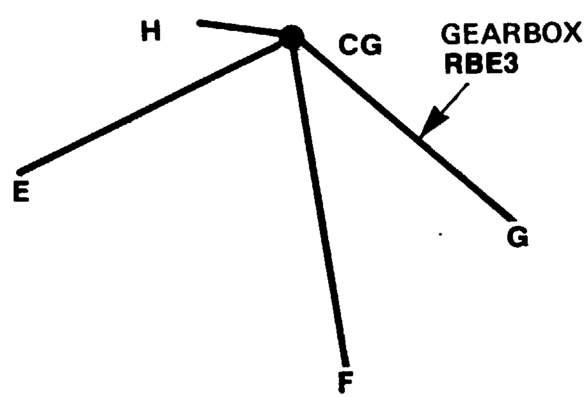
The intermediate gear box is mounted on the upper shear deck of the lower tail rotor pylon. The intermediate gear box is bolted to pads on the upper shear web at the points A, B, C, D. The loads from the gear box are transferred by the pads to the horizontal spar caps at the points E, F, G, H. In the NASTRAN model the intermediate gear box is represented by an RBE3 element attached directly to points on the spar caps.

STATIC MODELING GUIDES

Intermediate Gearbox







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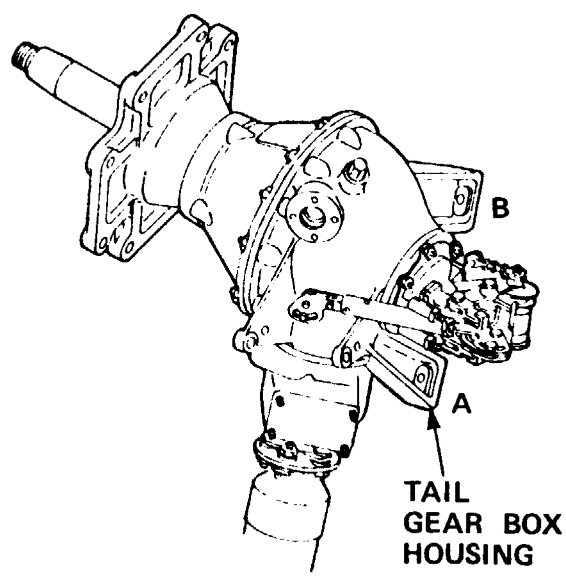
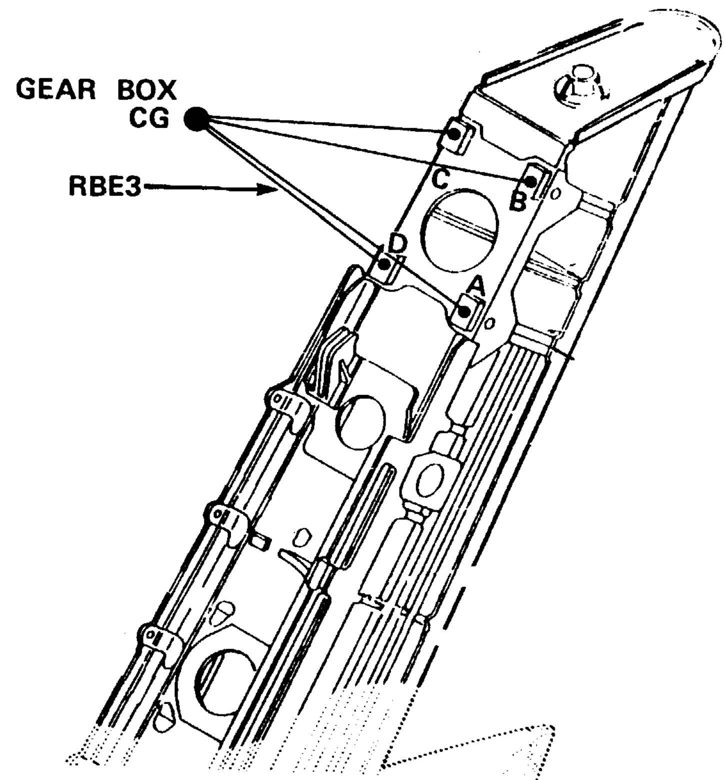
STATIC MODELING GUIDES
Tail Rotor Gearbox

The tail rotor gear box is mounted at the top of the forward spar of the tail rotor pylon. The gear box is represented by an RBE3 element attached directly to grid points on the spar caps.

STATIC MODELING GUIDES

Tail Rotor Gearbox



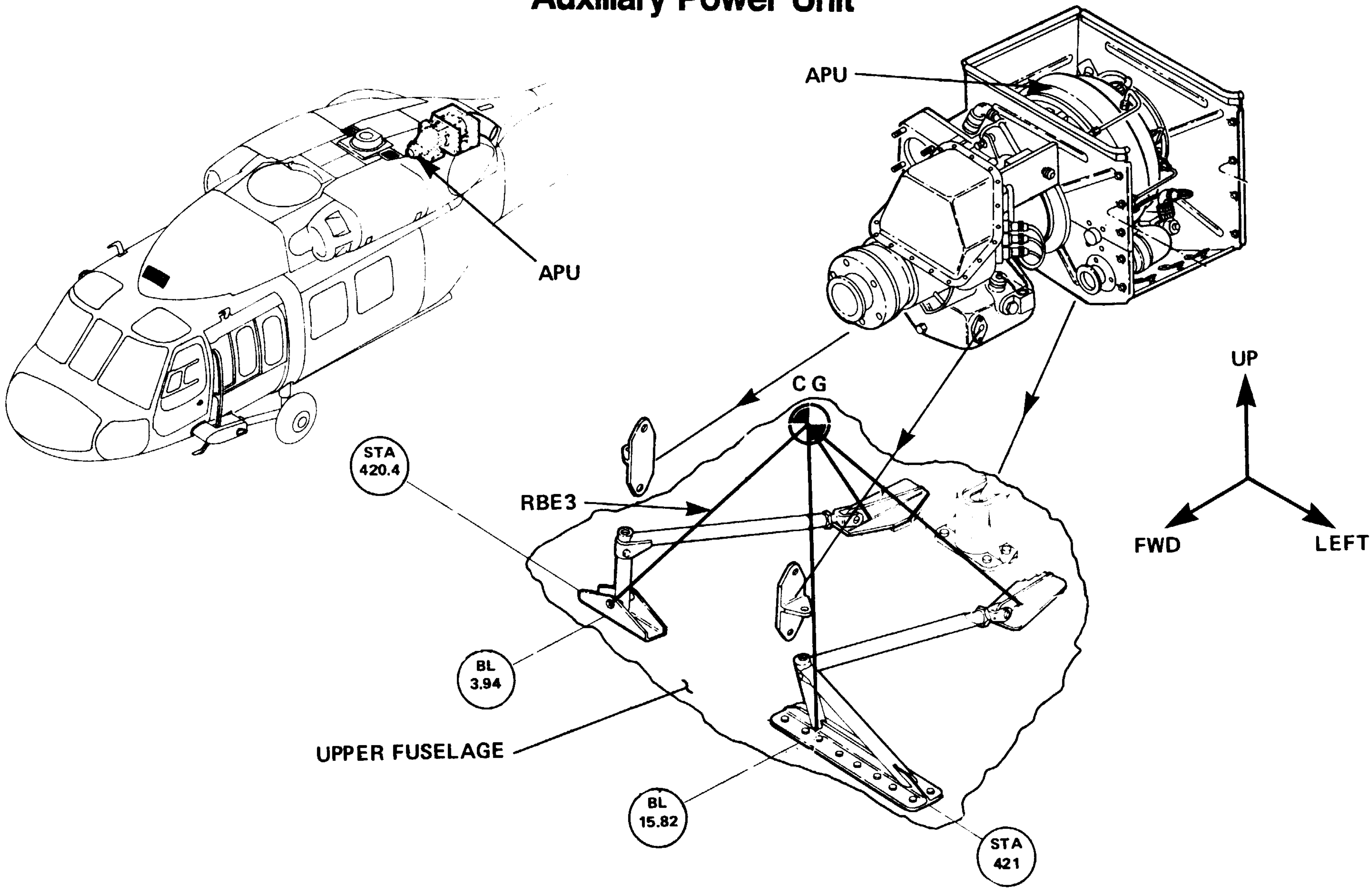


STATIC MODELING GUIDES
Auxiliary Power Unit

The auxiliary power unit (APU) is located on the roof of the transition section. It is supported on the bottom by struts connected to the airframe, and is attached to the firewall on its left hand side. The APU is represented in the NASTRAN model by an RBE3 element. As the firewall is not represented in the model, the RBE3 is connected only to the grid points on the outer shell of the model.

STATIC MODELING

Auxiliary Power Unit



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SECTION 4.2
MASS MODELING

MASS MODELING
Overview

The following steps are used to generate the NASTRAN mass model:

1. Three types of input are prepared for Program E94AB (Mass Properties/NASTRAN Interface Program):

   a. BLACK HAWK Main Weight Accounting File – this is essentially an organized list of all the mass items in the empty aircraft, broken down into very small parts (approximately 5000 items). The file contains the weight and center of gravity of each item.

   b. Geometric boundaries of the regions within which the distributed masses will be summed up into lumped masses.

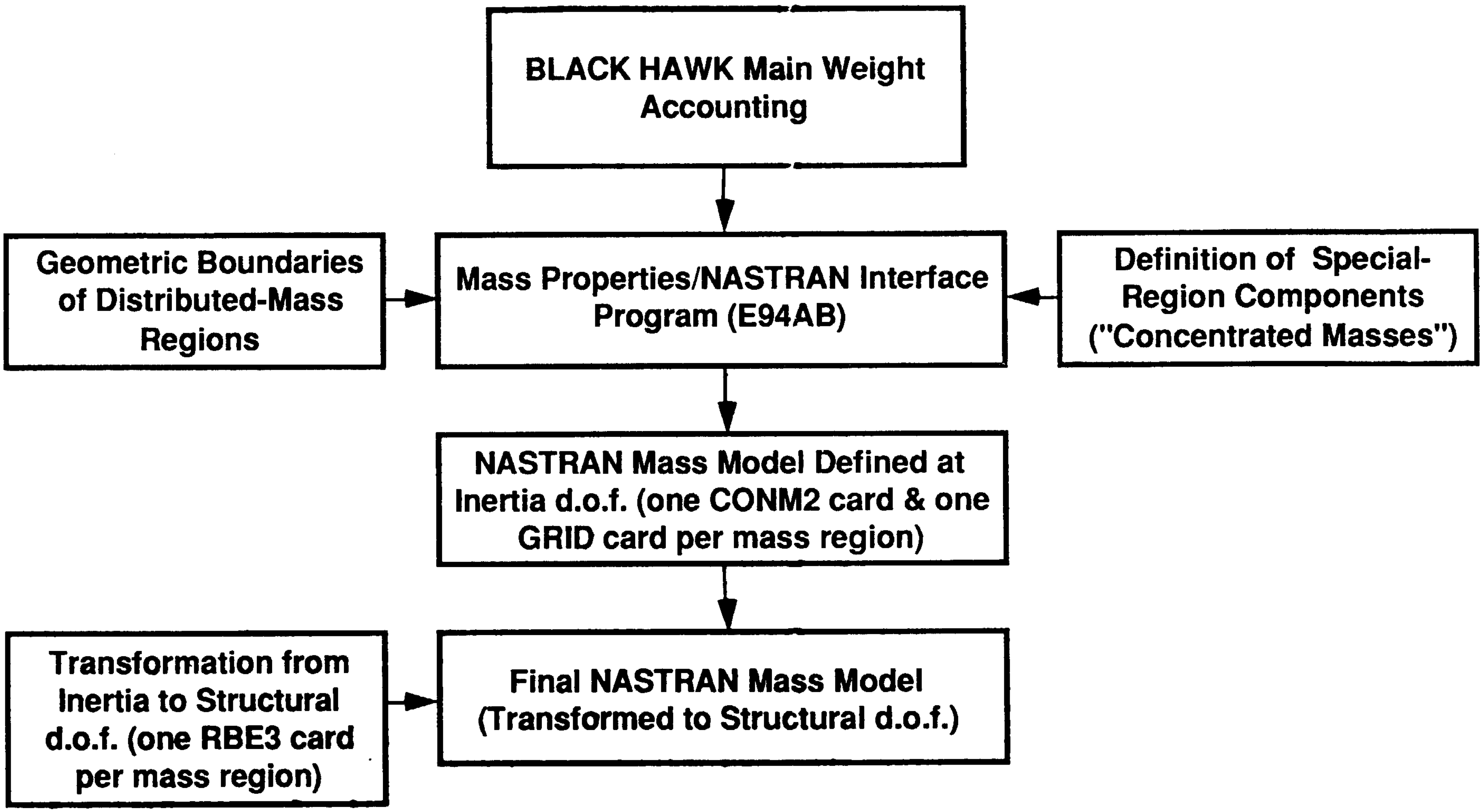
   c. A list of the "special–region" components ("concentrated masses"). These are components which the user wishes to separate out from the inertia–region summing–up process and assign to each its own particular center–of–gravity GRID point. This is usually done to improve the accuracy of the local inertia–load structural–stiffness interaction of a particularly heavy component or one whose attachment to the main structure is out of the ordinary.

2. Program E94AB is then run. Program output for each distributed–mass and "special–component" region consists of a NASTRAN GRID card defining the location of the center of gravity of the region, and a CONM2 card defining the summed up mass and moments of inertia of the region. Together these comprise a NASTRAN mass model (mass matrix) defined in terms of the degrees of freedom (d.o.f.) at the c.g.'s of the lumping regions.

3. To this model is added a set of RBE3 cards which define a transformation from mass c.g. d.o.f. to structural d.o.f. The final NASTRAN mass model is thus defined in terms of the FEM structural d.o.f.

MASS MODELING

Overview



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MASS MODELING
Representation of Distributed Mass

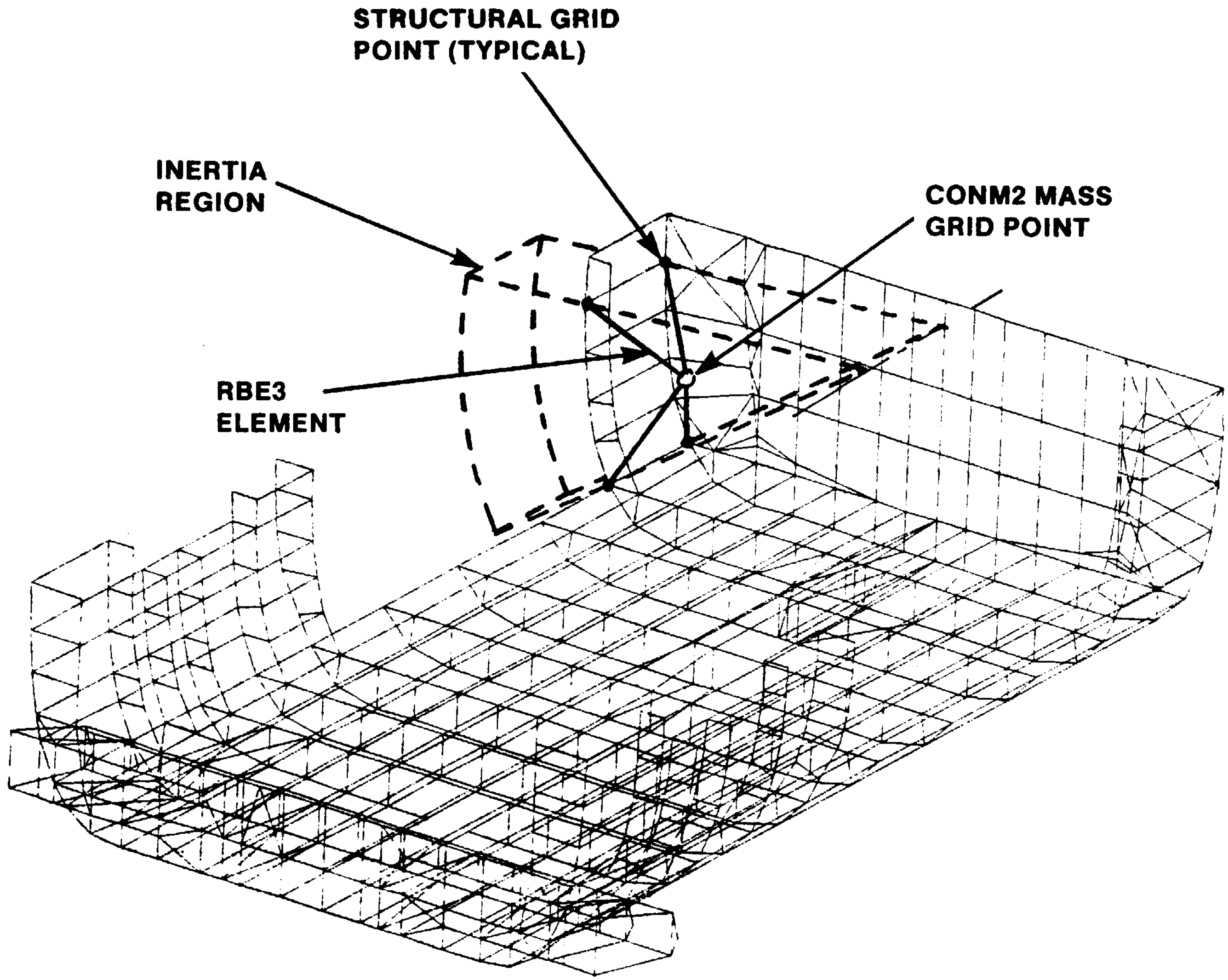
In defining the NASTRAN mass model, the aircraft is divided into a series of nonoverlapping "inertia regions" which completely enclose the volume of the aircraft. The accompanying figure shows the definition of a typical region in the cabin section. As shown by the dashed lines, the region encloses a pie shaped region between two frame stations. The apex of the region lies on the geometric longitudinal centerline of the airframe. The cylindrical surface of the region extends beyond the outer shell of the aircraft so that any distributed mass items lying outside of contour may be included in the region.

The mass properties of the region are computed taking into account weight, center of gravity, and moments of inertia for all distributed mass items that fall within the region. Output from the three dimensional mass and inertia modeling program (E94AB) for each region consists of a NASTRAN grid card defining the C.G. of the region and a NASTRAN CONM2 card defining the mass properties of the region.

To distribute the inertia load to the airframe model, the grid point at the C.G. is connected to the grid points on the airframe model by an RBE3 element. The formulation for the RBE3 element is such that it essentially acts as a "wiffle tree" to distribute the inertia loads to the grid points on the model and has no effect on the stiffness of the model.

MASS MODELING

Representation of Distributed Mass



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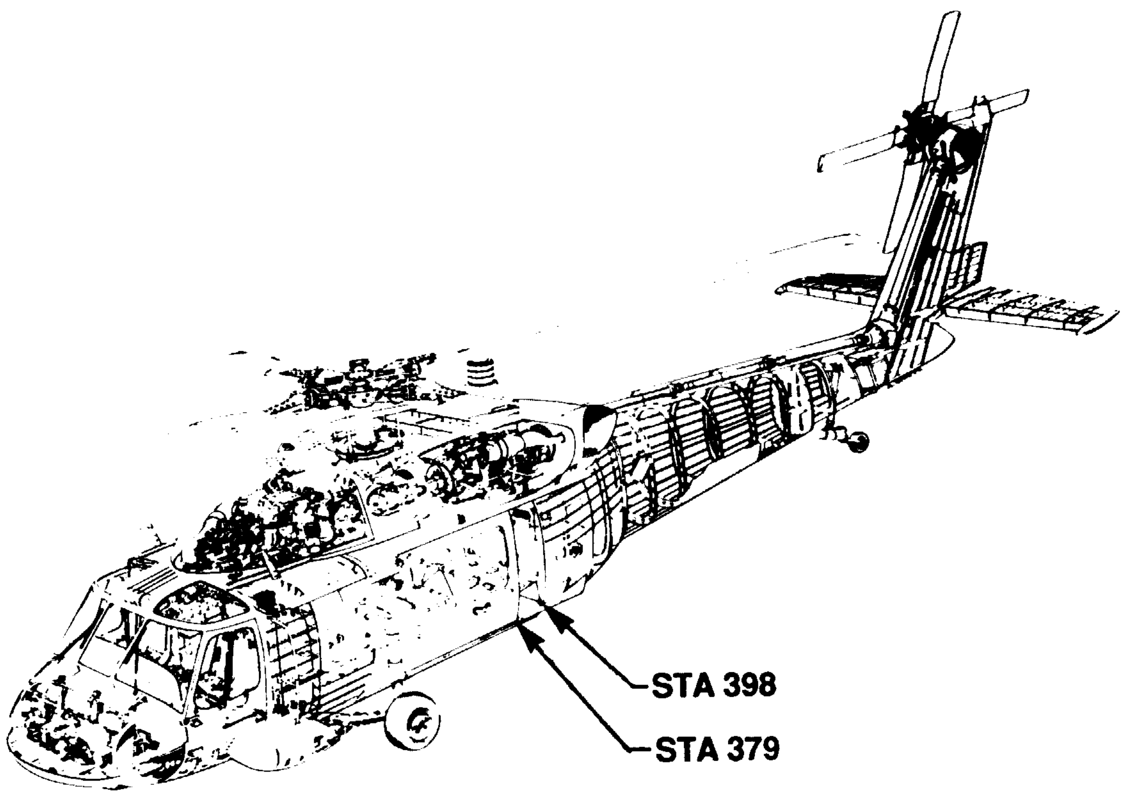
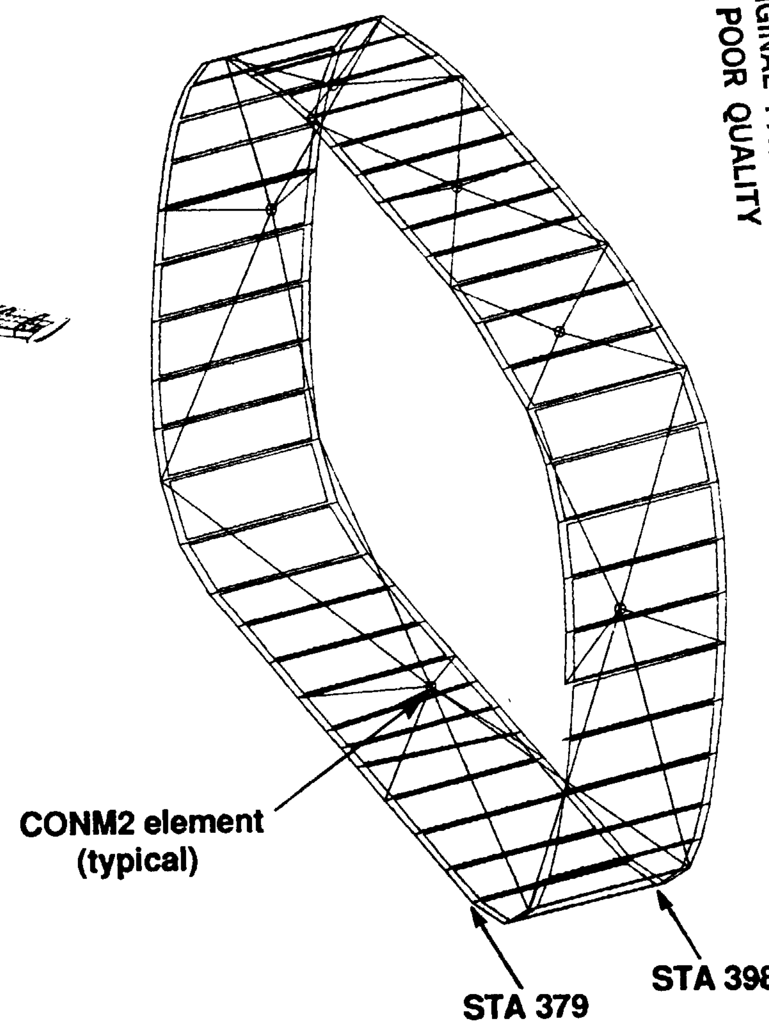
MASS MODELING
Mass Distribution in a Bay

The mass distribution within a bay or segment is represented by several inertia regions around the circumference of the bay. The mass for each region is connected by an RBE3 element to the user specified corner grid points that define the region. Additional grid points may be specified for the RBE3 element for improving the distribution of the inertia loads.

MASS MODELING GUIDES

Mass Distribution in a Bay





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MASS MODELING GUIDES
Treatment of Concentrated Mass Items

Both empty weight items and mission masses (useful load) are modeled as concentrated masses.

Empty weight concentrated masses include the following*:

Engines

Transmissions

Gear Boxes

Rotor Heads

Landing Gear

APU

Mission masses such as the crew and fuel are also treated as concentrated masses.

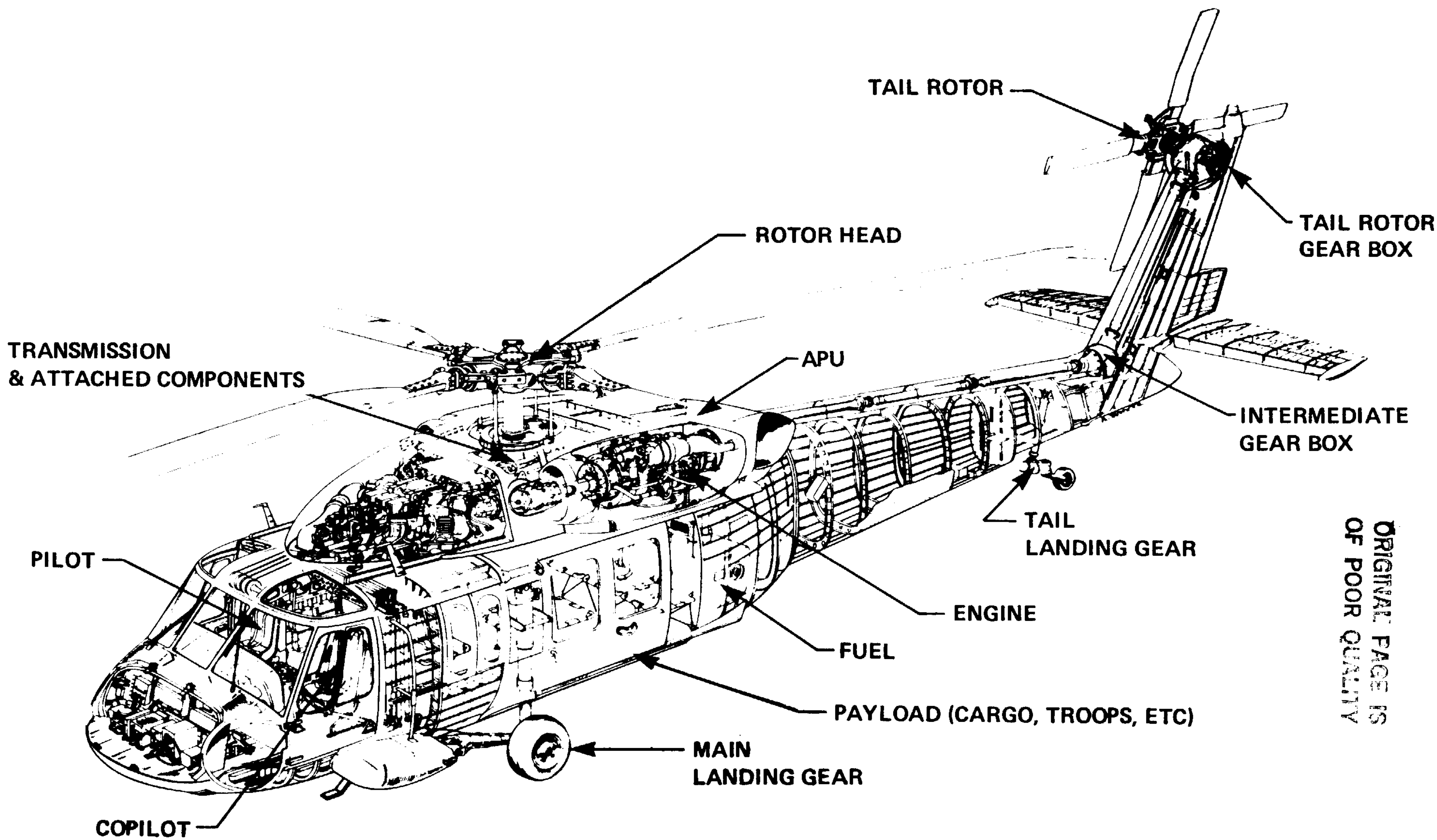
Most concentrated masses are represented by their actual mass and moments of inertia except the following:

- Rotor system items that are part of the flapping mass are combined into a single mass for which effective inertias are computed.
- Effective inertias are computed for the fuel quantity included in each design case.

* *In updating the mass model, the number of mass items treated as special regions was increased in order to more accurately reflect their influence in the vibrations model.*

MASS MODELING GUIDES

Treatment of Concentrated Mass Items



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SECTION 4.3
VIBRATION MODELING

VIBRATION MODELING
Changes from Static to Vibration Finite Element Model

The figure indicates the changes to convert from the statics FEM to a vibration FEM.

AIRCRAFT CONFIGURATION

The aircraft is analyzed in the free–free condition to simulate an inflight condition, free of grounding restraints. The vibration model will be run without SUPORT cards so that the near–zero frequency locations of the six rigid–body modes will serve as additional modeling checks.

An empty configuration is analyzed with no cargo and no fuel, and the vibration absorbers locked, to keep the emphasis on the modeling of the basic airframe structure.

MODELING

The major structural modeling difference between the static and vibration models is the skin effectiveness. The skins of the static model (represented by QUAD4's) are treated as shear–only material, in keeping with the assumption of buckled skin in severe maneuvers; the skins of the vibration model (also QUAD4's) are treated as a material which has both inplane shear and inplane axial stiffnesses, in keeping with the assumption of unbuckled (fully effective) skin in mild maneuvers.

The main rotor is treated as an actual hub weight and inertia plus 50% of the flapping weight of the blades, to simulate the expected shake test configuration.

VIBRATION MODELING

Changes from Static to Vibration Finite Element Model

Aircraft configuration

- Free–free condition
- Empty aircraft
- Vibration absorbers locked

Modeling

- Fully effective skin
- 50% of main rotor blade flapping weight

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VIBRATION MODELING GUIDES
Generalized Dynamic Reduction

The so-called generalized dynamic reduction method is used to reduce the number of degrees of freedom for a modal analysis. This is an assumed mode method wherein the assumed modes are approximate vibration modes which are obtained by inverse iteration. The number of approximate modes chosen is 1.5 times the number of accurate modes desired.

VIBRATION MODELING

Generalized Dynamic Reduction

$$\{U_f\} = [G]\{U_q\}$$

Static FEM DOF

Generalized coordinates for modal analysis

Reduction transformation

The columns of [G]:
- Approximate the lower modes of the structure
- Are obtained by inverse iteration
- Are equal in number to 1.5 x (number of accurate modes desired)

SECTION 4.4
DEMONSTRATION CASES

DEMONSTRATION REQUIREMENT

The demonstration requirement for the NASTRAN model of the UH-60A is to show that the model generates reasonable (error free) results for computations of (1) static internal member loads, (2) steady-state forced response to oscillatory excitation forces at the blade passage frequency applied at the main rotor hub, and (3) natural frequencies and mode shapes.

To meet the demonstration requirement, NASTRAN runs will be performed for the following:

1) Rigid Body Checks
2) Static Analysis for Internal Member Loads
3) Normal Modes Analysis
4) Forced Vibration Analysis

All demonstration cases will be performed using the latest version of MSC/ NASTRAN, which has been checked out and released for production usage at Sikorsky Aircraft. Rigid body checks and static analyses will be performed using DMAP Program SF24. This program, which was developed at Sikorsky Aircraft, is a modification of RIGID FORMAT 24, Static Analysis with Inertia Relief, which is standard in MSC/NASTRAN.

All runs will be performed using Sikorsky Aircraft computer facilities.

DEMONSTRATION REQUIREMENT

DEMONSTRATION REQUIREMENT

- Model of UH–60A generates reasonable (error–free) results for:
  - Static Internal Loads
  - Steady state forced response
  - Natural Frequencies and mode shapes

DEMONSTRATION CASES TO MEET REQUIREMENT

- Rigid body checks
- Static analysis for internal member loads
- Normal modes analysis
- Forced vibration analysis

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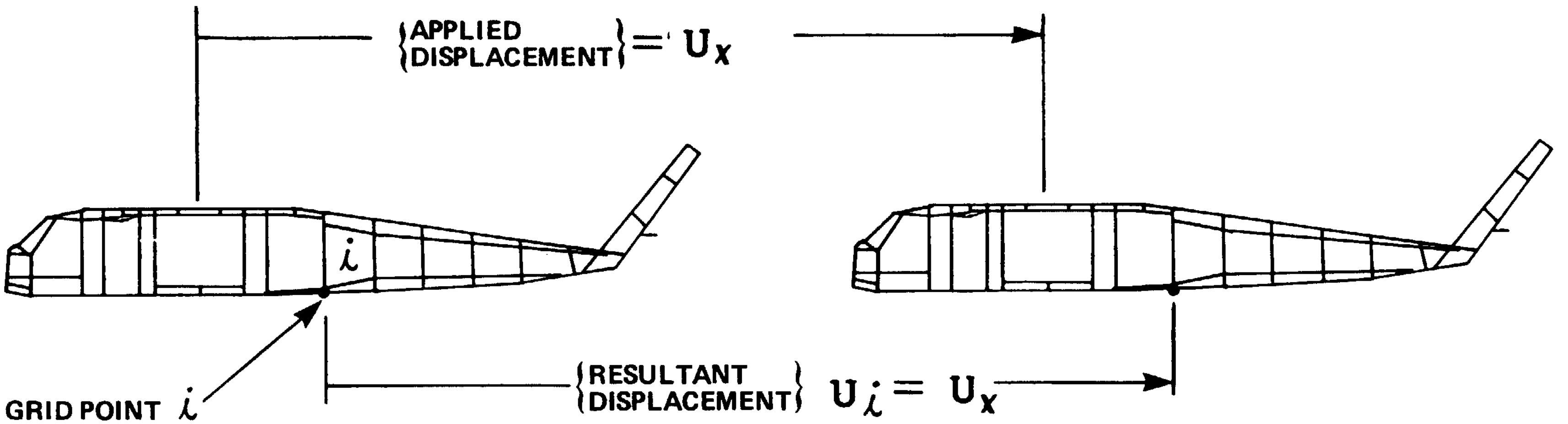
DEMONSTRATION CASES
Rigid Body Checks

In a rigid body check, the structural model together with all applicable multipoint constraint relations and rigid elements is considered to be a free body in space. No loads are applied to the model and all single point constraints, except those required to remove singularities in the stiffness matrix, are removed. If in this state the model is truly a free body with no inconsistent constraints applied to it, then it is capable of motion without internal stress. Thus, if a unit displacement is imposed at a given point of the model, then all points in the model must move in a manner consistent with the imposed displacement. In addition, all structural elements must remain unstressed. Any deviation from this indicates that the constraints applied to the model are inconsistent or that mechanisms exist in the model.

The accompanying figure indicates the items that are evaluated during the rigid body checks. Areas of the model for which modeling problems exist are identified and corrected. A modeling problem which is difficult to detect in rigid body checks is the identification of nearly singular degrees of freedom. These degrees of freedom, because of round–off errors in the computed displacements for large models, often appear to behave quite normally. Further attention is given to detecting these degrees of freedom in the initial static analysis runs and in those for modal analysis.

DEMONSTRATION CASES

Rigid Body Checks



ITEMS EVALUATED :

ABILITY OF MODEL TO SATISIFY RIGID BODY MOTIONS
CONSISTENCY OF SINGLE POINT FORCES OF CONSTRAINT
CONSISTENCY OF MULTIPOINT FORCES OF CONSTRAINT AND RIGID ELEMENTS
EQUILIBRIUM OF INTERNAL FORCES
CONDITIONING OF THE STIFFNESS MATRIX
MECHANISMS

DEMONSTRATION CASES
Static Internal Loads

The demonstration case for static internal loads will be for a 2.783g rolling pullup at an aircraft gross weight of 7631.69 kg (16825 lb.) and C.G. at 9.1491 m (360.2 in.).

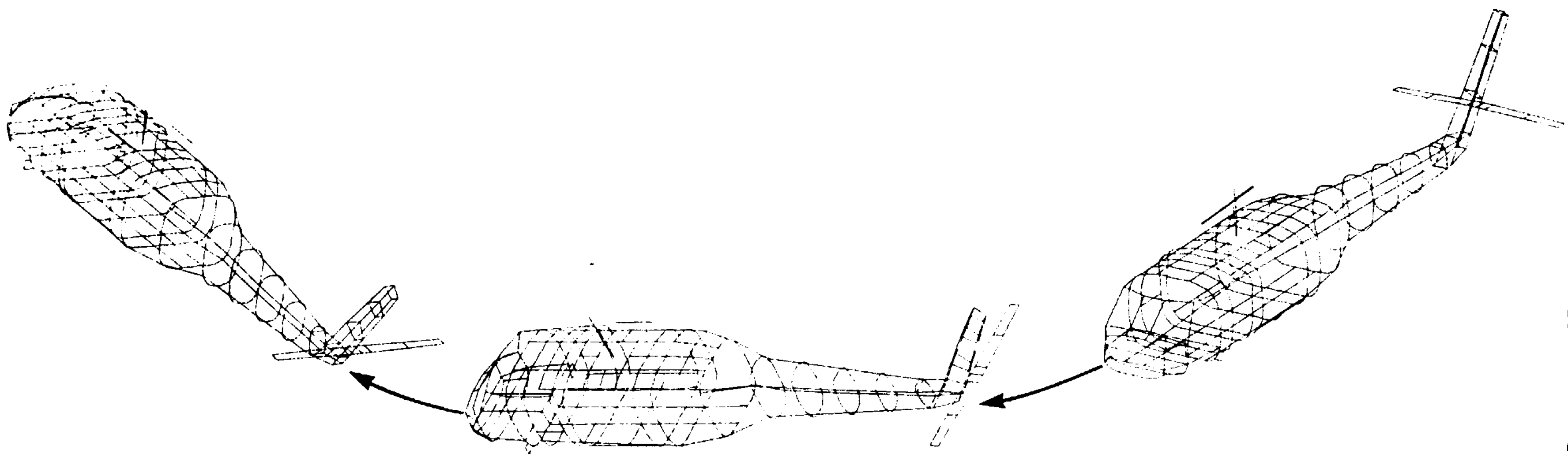
The analysis will be performed using the capabilities in NASTRAN for static analysis with inertia relief, as modified at Sikorsky Aircraft. These modifications consist of the recovery of the accelerations at the aircraft C.G. and all grid points in the model, the redistribution of the inertia loads from the mass points to the structural grid points, and the calculation of the G–set residuals.

The accelerations at the C.G. are compared to those predicted using a flight loads maneuver program, and serve to indicate the correctness of the mass and load distributions. The feature of the program which redistributes the inertia loads is part of a general capability of the program for calculating and redistributing MPCFORCES. This feature allows for the calculation of the G–set residuals, which is a compact summary of the force balance at each grid point.

Other information recovered from the NASTRAN output is indicated in the accompanying figure.

DEMONSTRATION CASES

Static Internal Loads



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INFORMATION TO BE RECOVERED FROM THE NASTRAN OUTPUT FILES

- Accelerations at C.G.
- Accelerations at Grid Points
- Inertia Loads
- MPCFORCES
- G–set Residuals
- Resultant Loads (Equilibrium)
- Displacements
- Load Vectors
- SPCFORCES
- Element Forces

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DEMONSTRATION CASES
Normal Modes Analysis

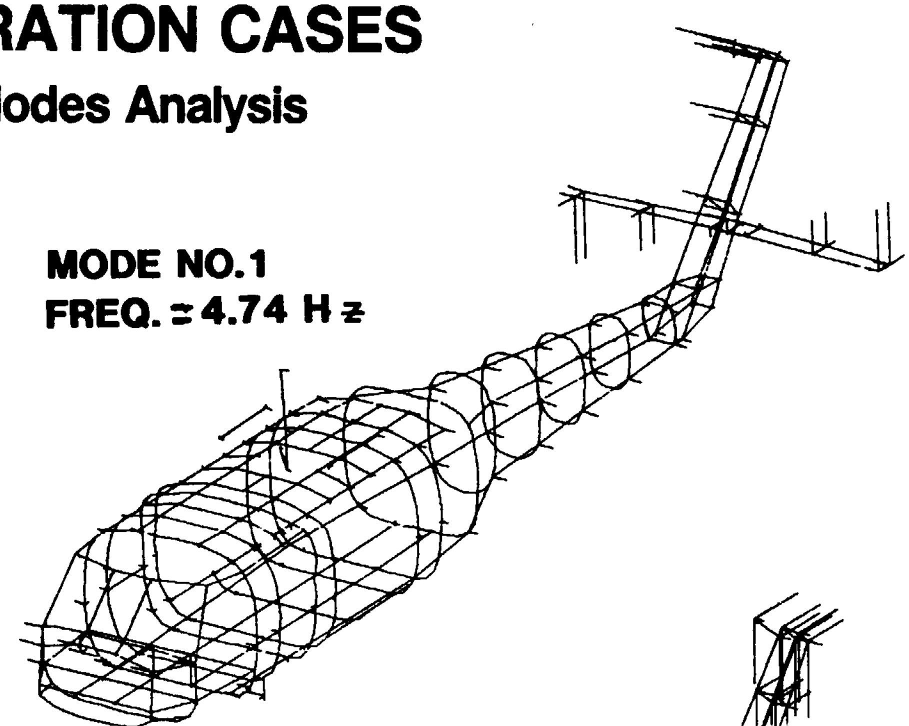
Airframe natural frequencies and modes will be calculated for an empty aircraft using the Givens method of eigenvalue extraction in MSC/NASTRAN, Rigid Format 3. NASTRAN frequency tabulation and modal vector printout will be obtained. Mode shape plots will be obtained using the NASTRAN automated plotting capability.

DEMONSTRATION CASES

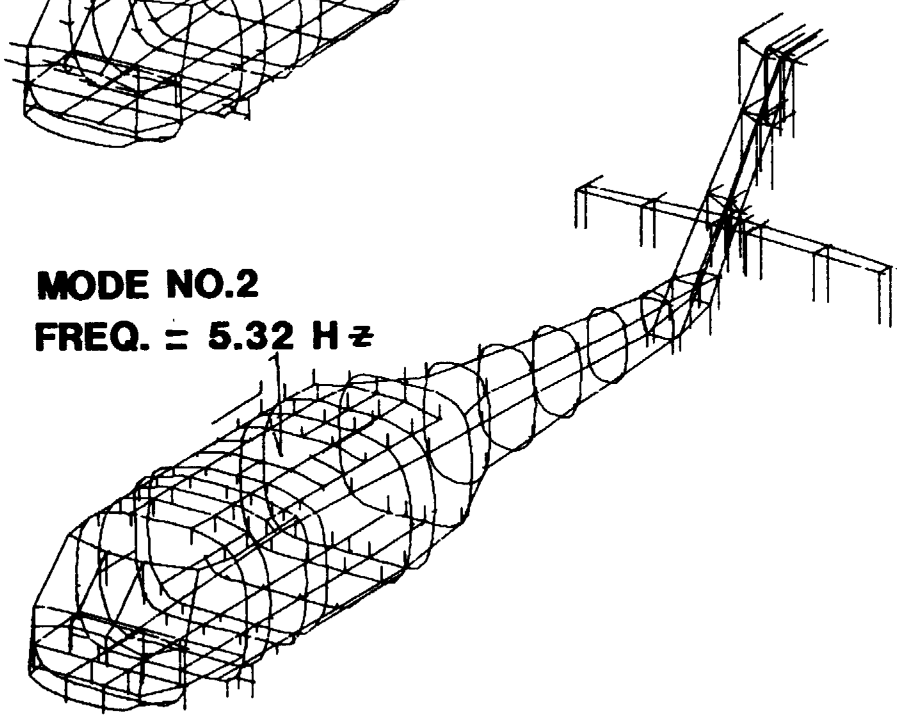
Normal Modes Analysis

MODE NO.	DESCRIPTION OF MODE	FREQ HZ
1	1st FUS. LATERAL BENDING	4.74
2	1st FUS. VERTICAL BENDING	5.32
3	STABILATOR ROLL	8.06
4	NOSE VERTICAL	8.86
5	TAIL VERTICAL BENDING	9.66
6	FUS. TORSION	9.93
7	STABILATOR YAW	10.04
8	2nd FUSELAGE LATERAL BENDING	11.34
9	2nd FUSELAGE VERTICAL BENDING	12.19
10	XSSN ROLL	12.63
11	XSSN PITCH	13.72
12	1st COCKPIT/CABIN TORSION	14.57
13	2nd COCKPIT/CABIN TORSION	15.08
14	XSSN VERTICAL	17.48
15	3rd FUS. VERTICAL BENDING	18.06
16	TAIL TORSION	21.81
17	CABIN SHEAR	22.74
18	2nd COCKPIT/CABIN TORSION	24.06
19	3rd LAT BEND	24.20

MODE NO.1
FREQ. = 4.74 Hz



MODE NO.2
FREQ. = 5.32 Hz



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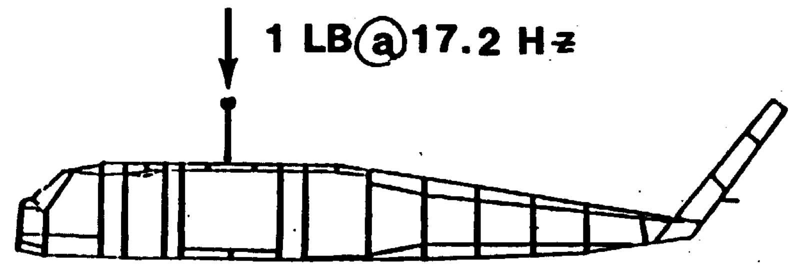
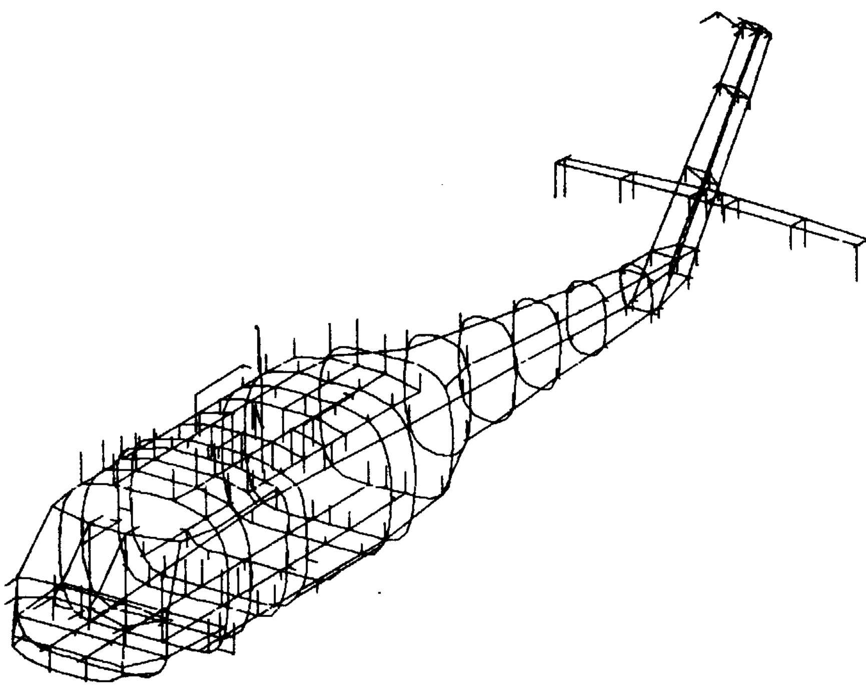
DEMONSTRATION CASES
Forced Vibration Analysis

Airframe forced vibration will be calculated using NASTRAN Rigid Format 30, which uses the natural modes as DOF. A unit oscillatory force will be applied in three directions, one at a time, at the main rotor head, at a frequency of b/rev. Output will be a NASTRAN listing of grid point accelerations in g's/lb and a plot of airframe accelerations.

DEMONSTRATION CASES

Forced Vibration Analysis





C O M P L E X   A C C E L E R A T I O N   V E C T O R
(MAGNITUDE/PHASE)

POINT ID.	TYPE	T1	T2	T3
164	G	8.811677E-02 79.1267	1.643081E-01 275.0657	2.668645E-01 222.1835
183	G	1.027470E-01 202.1624	1.525885E-01 261.3960	4.902033E-01 28.1345
829	G	6.781954E-02 120.5564	2.397333E-01 229.1558	3.528572E-01 53.3342
835	G	4.282122E-02 130.6900	2.190886E-01 228.8656	5.782259E-01 56.0632
923	G	7.713705E-02 109.6986	2.487633E-01 233.1317	3.967016E-01 48.8242
992	G	1.361281E-01 250.4383	1.719563E+00 236.1251	7.943220E-01 221.7320

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SECTION 4.5
PROJECTED MODELING SCHEDULE AND RESOURCES

STATIC MODELING SCHEDULE - PROJECTED

This figure shows the schedule and manhour estimates for the static (i.e., structural or stiffness) modeling effort for the BLACK HAWK. The schedule is shown for the four main stages of the modeling effort: (1) definition of the GRID point geometry, (2) numbering of the GRID points and elements and connectivity checks, (3) calculation of the element section properties, and, finally, (4) the rigid-body checks and static demonstration case.

STATIC MODELING SCHEDULE – PROJECTED

ACTIVITY	EST. M/H
1. Define geometry of GRID points	320
Cockpit Cabin Transition Tailcone Stabilator/Tail rotor pylon Special components	
2. Number GRID points & elements & connectivity checks	800
Cockpit Cabin Transition Tailcone Stabilator/Tail rotor pylon Special components	
3. Calculate element section properties	1700
Cockpit Cabin Transition Tailcone Stabilator/Tail rotor pylon Special components	
4. Rigid body checks and static Demonstration case	100
TOTAL M/H	2920

MONTH: 1 2 3 4 5 6 7 8 9 10 11 12

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MASS MODELING SCHEDULE - PROJECTED

The figure shows the schedule and the estimated manhours for the mass modeling of the BLACK HAWK. The mass modeling effort is based on using an existing BLACK HAWK weights file, which consists of a list of all the items in the aircraft, broken down to the detailed part level, along with the weight and center of gravity of each item.

The effort is broken down into three main steps. The first step involves defining the geometric boundaries of all the 3-dimensional pie-shaped regions of the fuselage in which the item masses will be summed. Also defined will be those special mass components which will be given their own center-of-gravity GRID points and thus will be excluded from the region summation process.

The second step involves running the Mass Properties/NASTRAN Interface (E94AB) Program using as input the data from Step 1 and the BLACK HAWK weights file. The output of this program is a set of NASTRAN CONM2 cards, which contain the mass and inertia properties of each lumped region (and each special mass component), and the corresponding center-of-gravity GRID cards.

The final step in creating the NASTRAN mass model involves the generation of the RBE3 elements which connect the center-of-gravity GRID points to the surrounding GRID points of the stiffness model. These elements define the motion of each mass GRID point as an average of the motions of the structural GRID points to which it is connected.

MASS MODELING SCHEDULE – PROJECTED

ACTIVITY		EST. M/H													
1. Define geometry of distributed mass regions and define special mass regions (input for Mass-Properties/NASTRAN Interface Program [E94AB])		40													
2. Run program E94AB		360													
– Output CONM2 cards & corresponding GRID cards (Mass, c.g., and inertias of distributed mass in each region)															
3. Generate RBE3 cards to connect above mass GRID points to structural GRID points		40													
TOTAL M/H		440													
MONTH				1	2	3	4	5	6	7	8	9	10	11	12

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VIBRATION MODELING SCHEDULE – PROJECTED

The figure shows the estimated schedule and manhours for the efforts required to conduct the BLACK HAWK finite–element model vibration analysis under the current NASA contract.

VIBRATION MODELING SCHEDULE - PROJECTED

ACTIVITY	EST. M/H												
1. Static FEM coordination	280												
2. Modification of FEM for vibration	160												
3. Prepare data for modal analysis A. Transfer FEM to dynamics TSO file B. JCL C. Case control deck D. Plot set, including PLOTEL cards E. Bulk data cards, freq.	120												
4. Computer solution, modal analysis demonstration A. Run case w/o support card B. Rigid-body freq. check C. SPC force check D. Freq. & mode shapes check (no non-physical low-freq. local modes) E. Reruns correcting errors	160												
5. Computer solution, forced response demonstration A. Prepare bulk data force input B. Prepare case control C. Run case & check results D. Reruns correcting errors	80												
TOTAL M/H	800												
MONTH		1	2	3	4	5	6	7	8	9	10	11	12

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SECTION 5.0
UH–60A NASTRAN MODEL DOCUMENTATION

UH-60A NASTRAN MODEL
Documentation

This section contains a description of the UH-60A NASTRAN model developed during this task. It also illustrates the extent that the modeling guides given in Section 4.0 were actually implemented, and also shows the results obtained with the model.

Included in this section is documentation to describe:

1) Actual versus planned modeling guides.
2) The static, mass, and vibration models.
3) Demonstration cases used to assess the accuracy of the model.
4) A comparison of the actual modeling effort (both manhours and schedule) to the effort as originally estimated.

UH-60A NASTRAN MODEL

Documentation

Documentation

- Actual versus planned modeling guides

- Model description
  - Statics model
  - Mass model
  - Vibration model

- Demonstration cases
  - Static analysis for internal member loads
  - Normal modes analysis

- Comparison of planned and actual modeling efforts

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SECTION 5.1
ACTUAL VERSUS PLANNED MODELING GUIDES

ACTUAL VERSUS PLANNED MODELING GUIDES

One of the main requirements of this project was that the UH-60A NASTRAN model would be formulated according to the modeling guides defined in Section 4.0 and evaluated on that basis. To a large extent the model has been formulated using these guidelines. However, during the development of the model it became apparent that by deviating from the modeling plan the model would more closely represent the actual behavior of the structure. Major departures from the modeling plan occurred during the formulation of the static and mass models. The vibrations model was formulated using the guidelines established in Section 4.3.

ACTUAL VERSUS PLANNED MODELING GUIDES

- Major departures from the modeling guides were made for:
  - Static model
  - Mass model
- Vibration model follows the vibration modeling guides

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ACTUAL VERSUS PLANNED MODELING GUIDES
STATICS MODEL

Major deviations from the modeling guides for the statics model include:

1) All deep built-up and machined frames and beams were modeled as built-up members (i.e., BAR elements with area properties to represent the caps, and QUAD4 elements to represent the webs). This departure was made to maintain continuity in the model between connecting structural members (e.g. the cabin floor and the cabin frames and beam) without resorting to the extensive use of rigid elements. Shallow-depth frames and beams were represented by BAR elements with area and inertia properties.

2) The leading and trailing edge fairings of the stabilator were felt to have an appreciable effect on the stiffness of the stabilator, and were included in the modeling of the stabilator.

3) The attachment of the tailcone and transition sections at Station 485 was represented in the NASTRAN model by MPC equations to more closely represent the actual connection in the airframe.

ACTUAL VERSUS PLANNED MODELING GUIDES

Statics Model

- All major frames and beams are modeled using guides for built–up members
- Stabilator leading and trailing edge fairings to be primary structure
- Transition section and tailcone models attached together using MPC equations

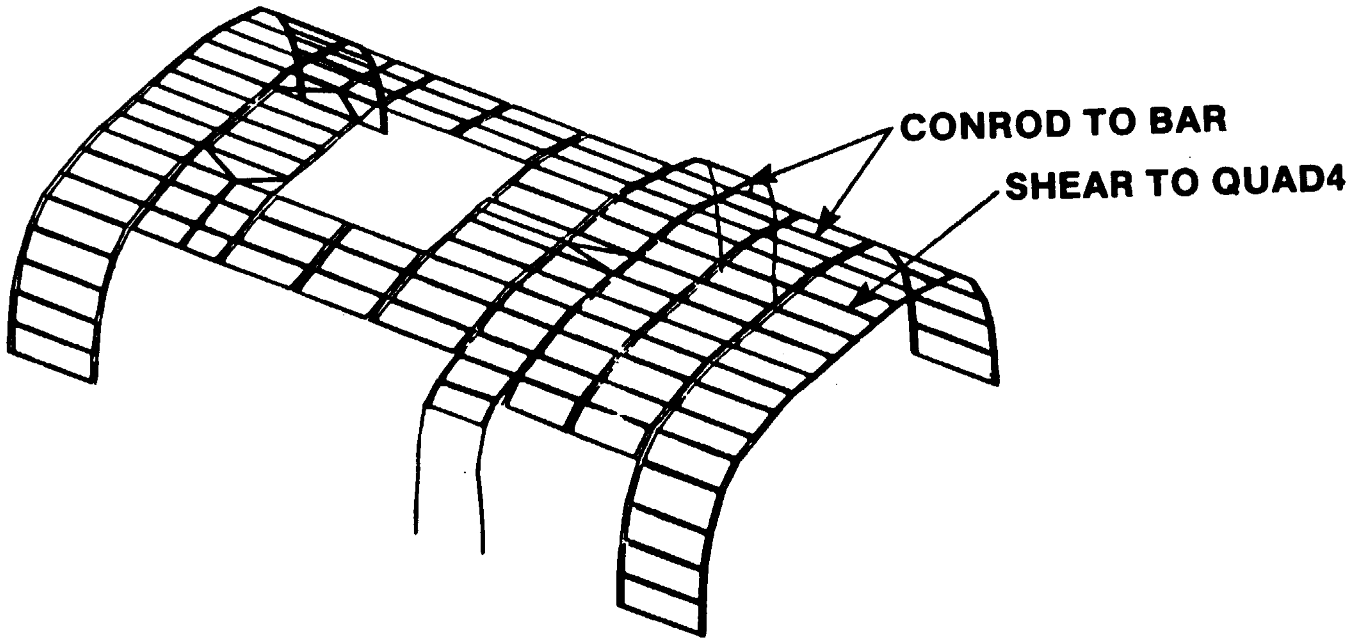
STATIC MODELING
ELEMENT TYPE CHANGES FOR CORRELATION STUDY

Stringers and longerons are structural members which are common in the construction of semi-monocoque, sheet metal airframe structures. Because these members primarily resist axial loads, they are typically modeled with CONROD elements when forming a finite element model for static analysis. However, there is reason to believe that for vibration analyses, secondary stiffnesses associated with bending and transverse shear may be of importance. To enable the finite element model to be later used in an analytical assessment of these secondary effects, all CONROD elements in the model will be replaced with BAR elements. During the initial development of the model the reference vectors and offsets, as well as the axial, bending, torsional and shear stiffness properties will be calculated. However, for the demonstration test cases, only the reference vectors and axial stiffnesses will be used.

In addition, to facilitate the changeover to the vibrations model, all shear panels will be replaced with QUAD4 elements. For the statics model, only shear stiffness will be provided for these elements.

STATIC MODELING

Element Type Changes For Correlation Study



- TO ALLOW FOR THE INVESTIGATION OF THE EFFECTS OF SECONDARY STIFFNESSES ON THE PREDICTED VIBRATION MODES AND TO SIMPLIFY THE CHANGE OVER TO THE VIBRATIONS MODEL, ELEMENT TYPES WILL BE CHANGED.
  - CONROD TO BAR
    - REFERENCE VECTORS, OFFSETS, INERTIA, AXIAL AND SHEAR STIFFNESSES WILL BE CALCULATED.
    - ONLY AXIAL STIFFNESS WILL BE USED IN THE MODEL
  - SHEAR TO QUAD4
    - ONLY SHEAR STIFFNESS TO BE USED IN THE MODEL.

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ACTUAL VERSUS PLANNED MODELING GUIDES
MASS MODEL

Major deviations from the modeling guides for the mass model include:

1) The number of inertia regions was increased from 266 to 413.

2) The number of mass items treated as large mass items was increased from 20 to 35 in order to more accurately include their effect in the NASTRAN Model.

ACTUAL VERSUS PLANNED MODELING GUIDES

Mass Model

- The number of inertia regions was increased from 266 to 413
- The number of mass items treated as "Special Regions" was increased from 20 to 35.

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SECTION 5.2
STATIC MODELING

UH-60A NASTRAN MODEL
STATICS MODEL

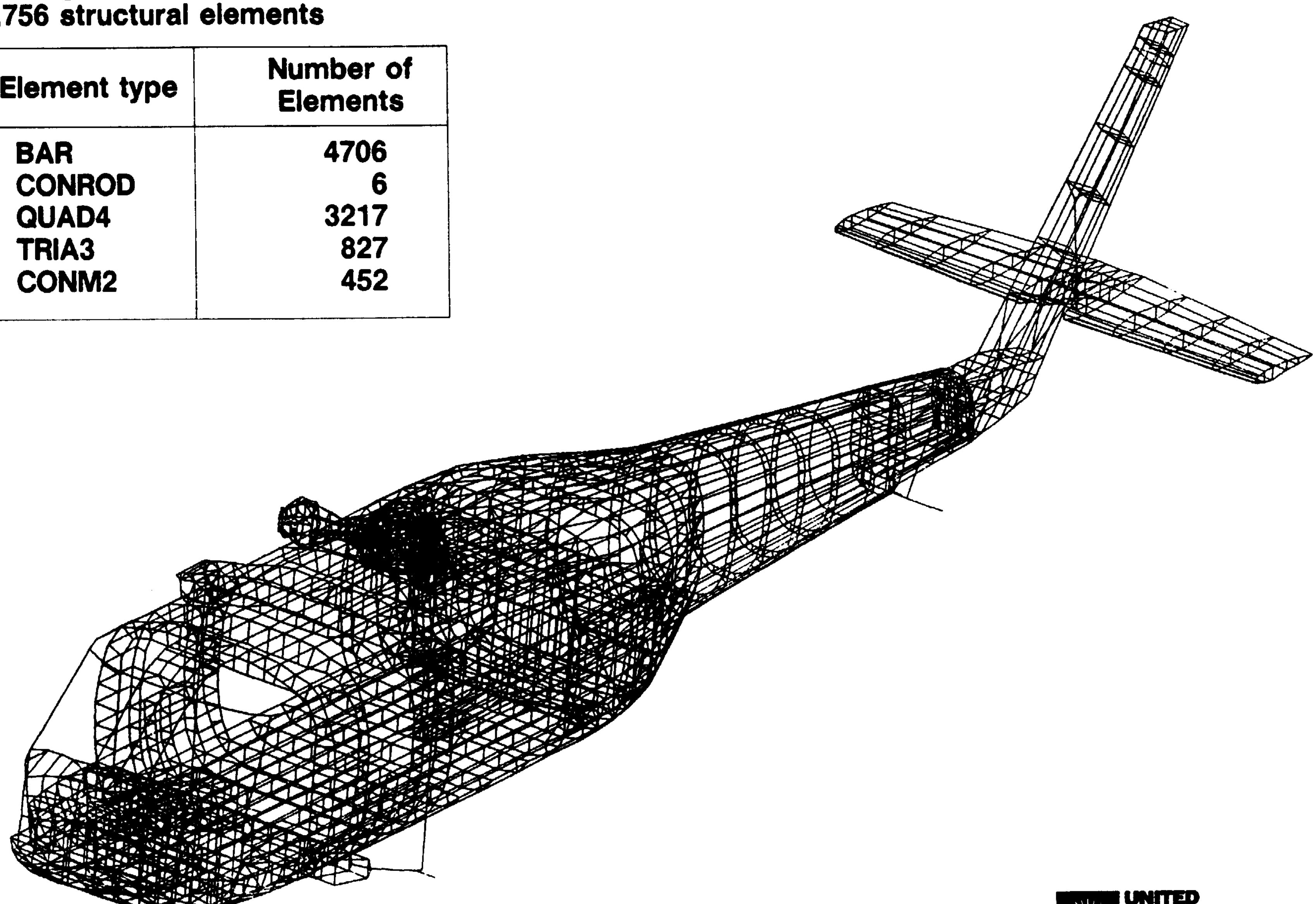
The accompanying figure shows the UH-60A NASTRAN model developed during this task. The model contains 4341 grid points and 8756 structural elements. The mass distribution used for the mass model consists of 452 mass points. The mass distribution is used for both static analysis with inertia relief and vibration analysis. Subsequent figures in this subsection illustrate the models of the subassemblies described in Section 3.0.

UH-60A NASTRAN MODEL

Statics Model

NASTRAN model
4,341 grid point
8,756 structural elements

Element type	Number of Elements
BAR	4706
CONROD	6
QUAD4	3217
TRIA3	827
CONM2	452



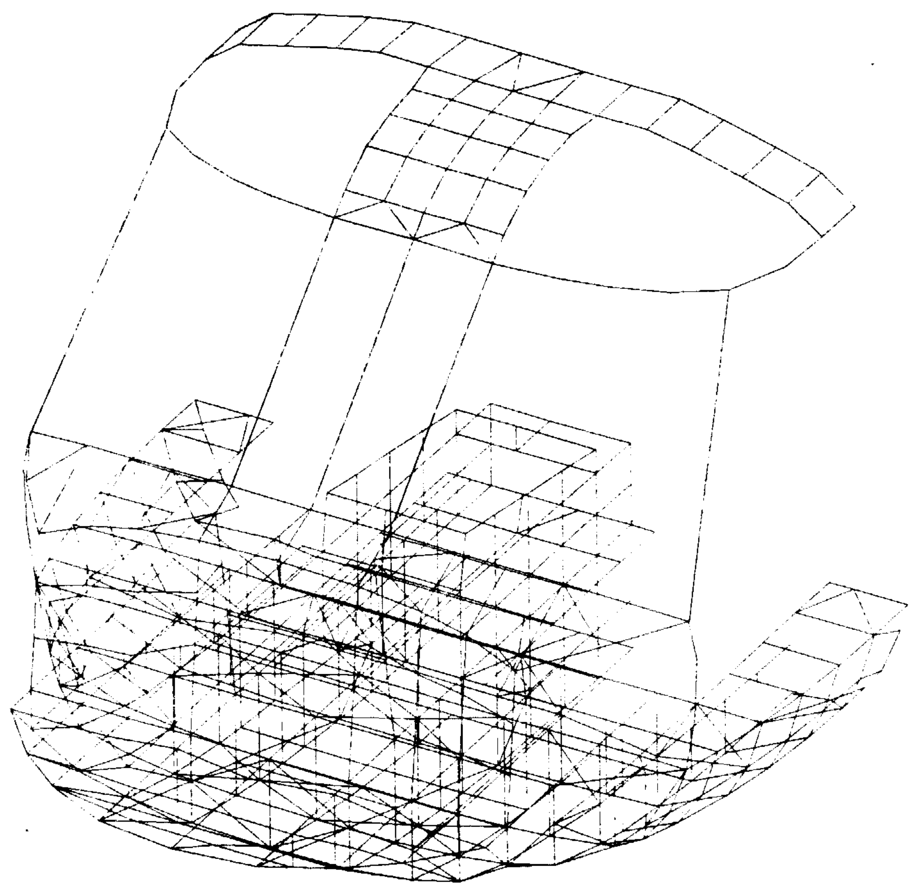
United Technologies Sikorsky Aircraft

UH-60A NASTRAN MODEL
COCKPIT

The accompanying figure shows the NASTRAN model of the UH-60A cockpit structure shown in the illustration on Page 27. Major improvements from the previously developed finite element model include the addition of the canopy and framing members of the windshields, and the lower tub structure forward of Station 4.70 m (185.0 in.).

UH-60A NASTRAN MODEL

Cockpit

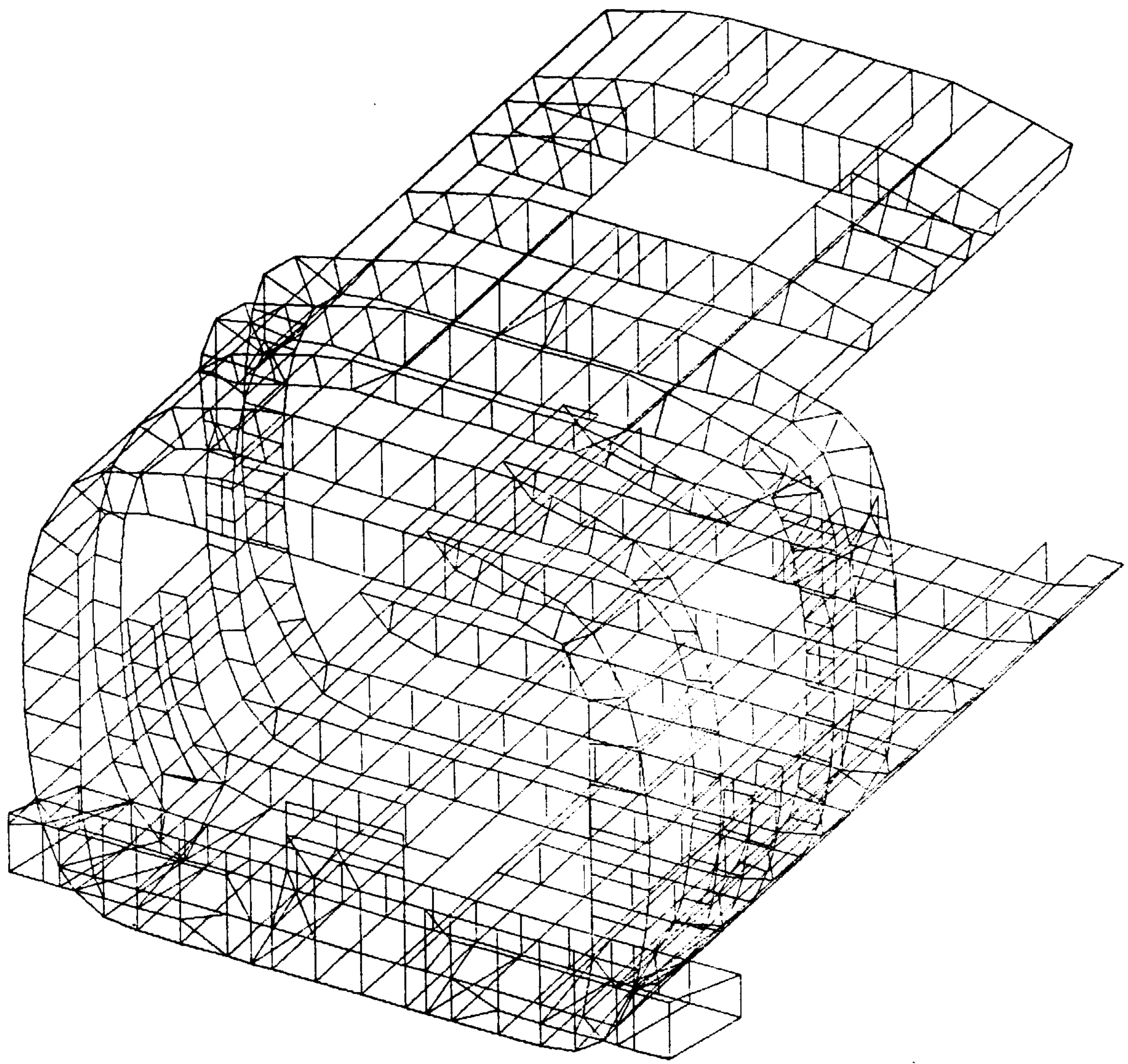


UH–60A NASTRAN MODEL
CABIN

The accompanying figure shows the NASTRAN model of the UH–60A cabin structure shown in the illustration on Page 31. For convenience the upper roof structure between Stations 9.63 m (379 in.) and 10.11 m (398 in.) has been included in the transition section model. The major departure from the previous NASTRAN model is the representation of all beams and frames as built–up structures.

UH-60A NASTRAN MODEL

Cabin



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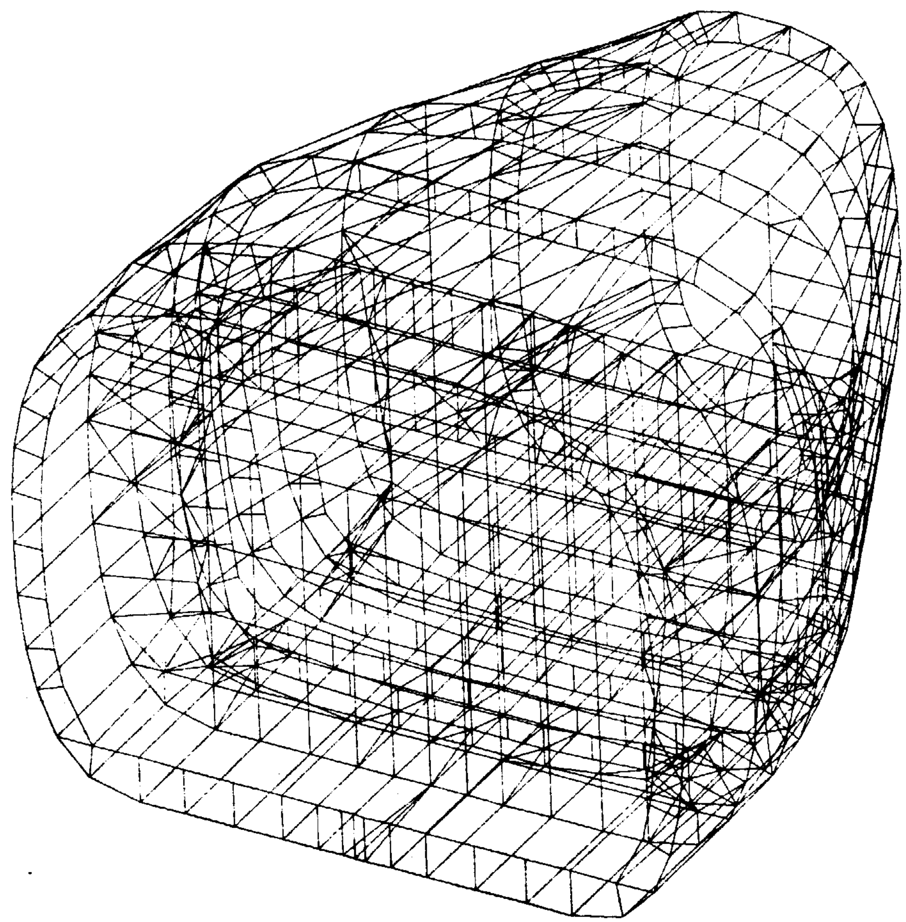
C.3

UH–60A NASTRAN MODEL
TRANSITION SECTION

The accompanying figure shows the NASTRAN model of the UH–60A transition section structure as shown in the illustration on Page 37.

UH-60A NASTRAN MODEL

Transition Section



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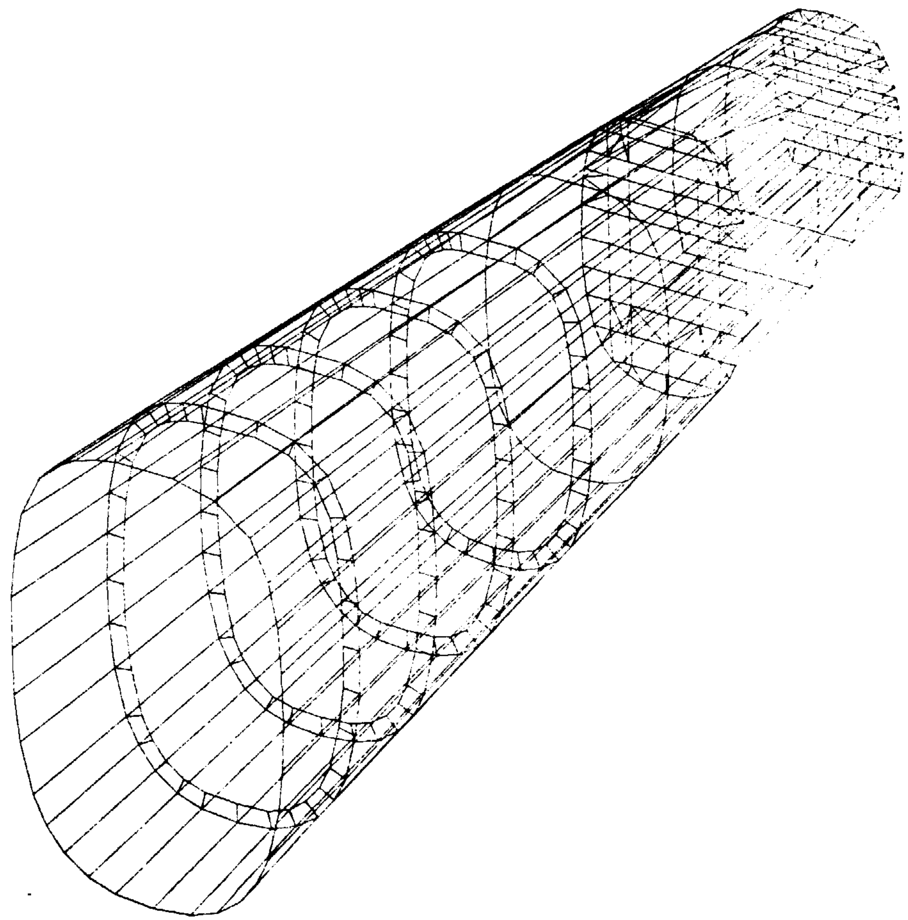
UH-60A NASTRAN MODEL
TAILCONE

The accompanying figure shows the NASTRAN model of UH-60A tailcone structure from Station 12.32 m (485 in.) to the forward fold bulkhead at Station 16.48 m (648.0 in.). The actual structural arrangement for the tailcone is shown in the figure on Page 41. Using the modeling procedure given on Page 115, the floating frames are modeled with BAR elements lying along the neutral axes of the frames. BAR elements connect points on the frame with the corresponding points on the outer shell to transfer radial and stringer axial loads to the frames.

UH-60A NASTRAN MODEL

Tailcone



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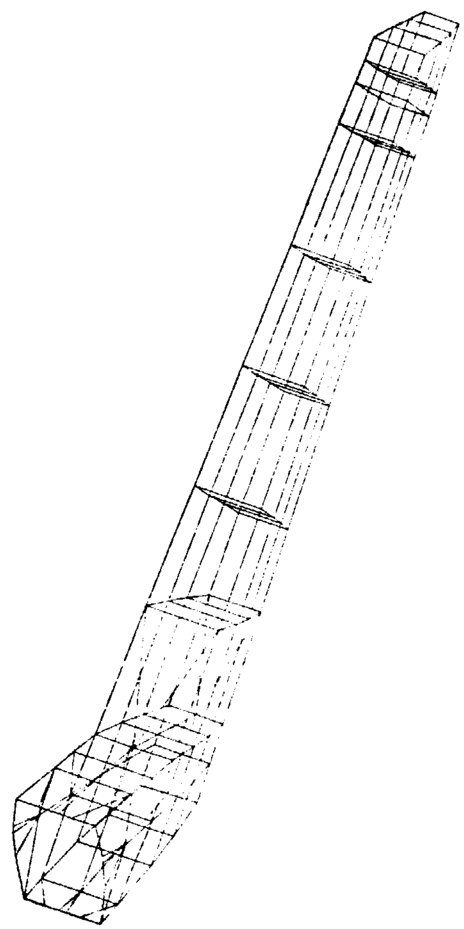
UH-60A NASTRAN MODEL
TAIL ROTOR PYLON

The accompanying figure shows the NASTRAN model of the UH-60A tail rotor pylon structure as shown in the illustration on Page 45.

UH-60A NASTRAN MODEL

Tail Rotor Pylon



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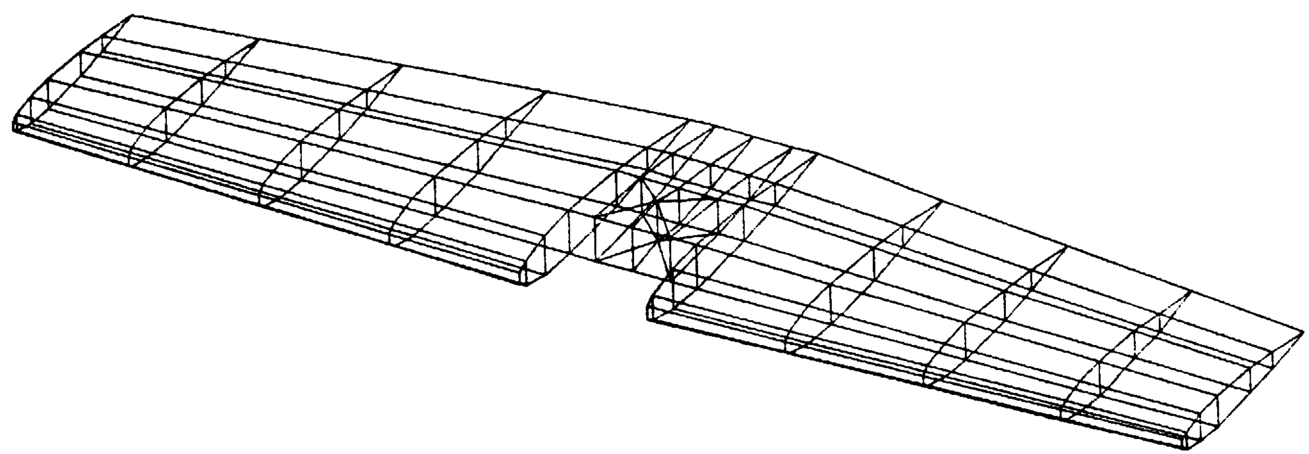
UH-60A NASTRAN MODEL
STABILATOR

The accompanying figure shows the NASTRAN model of the UH-60A stabilator as shown in the illustration on Page 49.

UH-60A NASTRAN MODEL

Stabilator



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SECTION 5.3
MASS MODELING

MASS MODELING
BLACK HAWK WEIGHT AND INERTIA

Mass modeling is based on data for the No. 640 production BLACK HAWK Serial No. 84-24012 weight empty. This figure presents the weight and inertia for this aircraft. It should be noted that this data is for the aircraft with only 50% of the flapping mass of the main rotor blades included which reduces the weight of the aircraft by 264 kg (581 lbs). In addition, the weight empty is further reduced by 201 kg (444 lbs) to take into account avionics and other equipment removed from the test article prior to testing.

MASS MODELING

Black Hawk Weight And Inertia

Empty weight*	4501 kg.	9902 lbs.
Horizontal C.G.	Sta 9.114 m.	Sta 360.0 in.
Lateral C.G.	BL 0.002 m.	BL 0.09 in.
Vertical C.G.	WL 6.629 m	WL 261.0 in.
Roll inertia	4989 kg–m^2	1.7013×10^7 lbs–ft^2
Pitch inertia	45,573 kg–m^2	1.5540×10^8 lbs–ft^2
Yaw inertia	43,486 kg–m^2	1.4829×10^8 lbs–ft^2

* Reduced by 50% of flapping mass

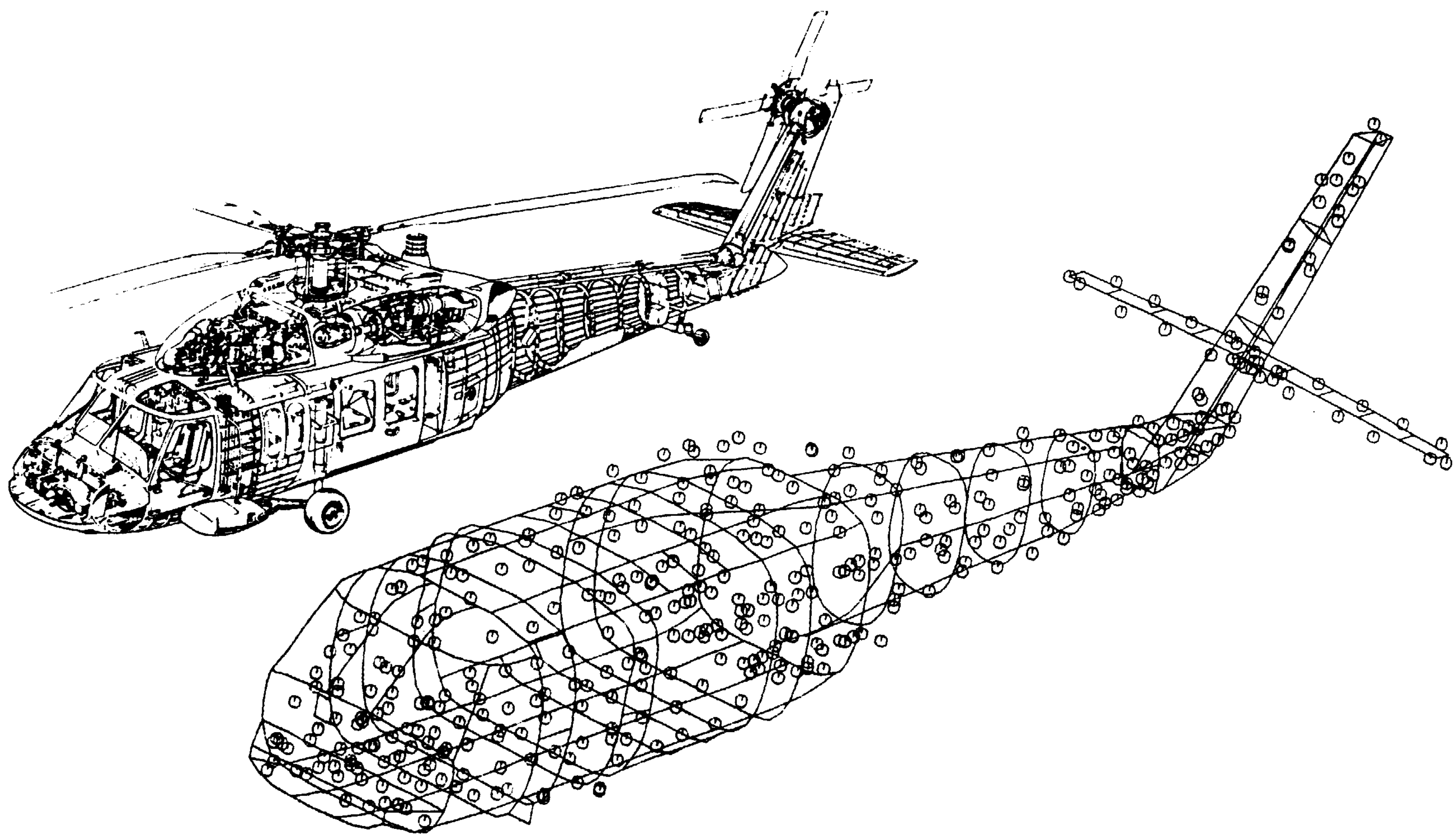
MASS MODELING
CENTER-OF-GRAVITY GRID POINTS FOR DISTRIBUTED-MASS REGIONS

In the nine bays of the cockpit, each bay is divided into 8 or 10 regions. In the cabin and transition sections (having eight and nine bays, respectively), each bay is divided into 12 regions; in the nine bays of the tailcone, 8 regions per bay; in the thirteen bays of the tail rotor pylon, 4 per bay; and in the fourteen bays of the stabilator, 2 per bay.

This adds up to a total of 422 regions whose center-of-gravity GRID points are indicated in the figure.

MASS MODELING

Center-of-Gravity Grid Points For Distributed-Mass Regions



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MASS MODELING
"SPECIAL-REGION" MASS COMPONENTS

Certain mass items were taken out of the regional mass–summation process just described and summed instead into special component regions identified by the program user. This was done because they belonged to a component or "special region" which it was desired to handle in a special way. Each of these special region masses (sometimes called concentrated masses) was given its own center–of–gravity GRID point.

The accompanying figure gives a list of mass components that were singled out as special regions in the present BLACK HAWK FEM. Their locations are shown in the figure on Page 223.

MASS MODELING

“Special–Region” Mass Components

“Special Region’ Mass Components	Weight (kg)	Weight (lbs)
Main rotor hub, exclusive of blades	245	539.0
Main rotor blades (50%of static blade masses)	263	578.6
Main transmission – divided into 3 mass points	390, 142, 155	858.0, 312.4, 341.0
Engines (2)	198 (2)	435.6 (2)
Main landing gears (2)	65 (2)	143.0 (2)
Tail landing gear	31	62.2
APU	63	138.6
Intermediate gearbox	22	48.4
Tail rotor gearbox	64	140.8
Tail rotor	56	123.2
Vibration absorbers, movable mass (3)	30, 31, 29	66.0, 68.2, 63.8
Cargo doors (2)	28 (2)	61.6 (2)
Cockpit doors (2)	14 (2)	30.8 (2)
Pilot seat	55	121.0
Copilot seat	55	121.0
Oil cooler	22	48.4
Cockpit mid–shelf	11	24.2
Bifilars	67	147.4
Fuel tanks (2)	71, 73	156.2, 160.6
TOTAL	2485	5467.0

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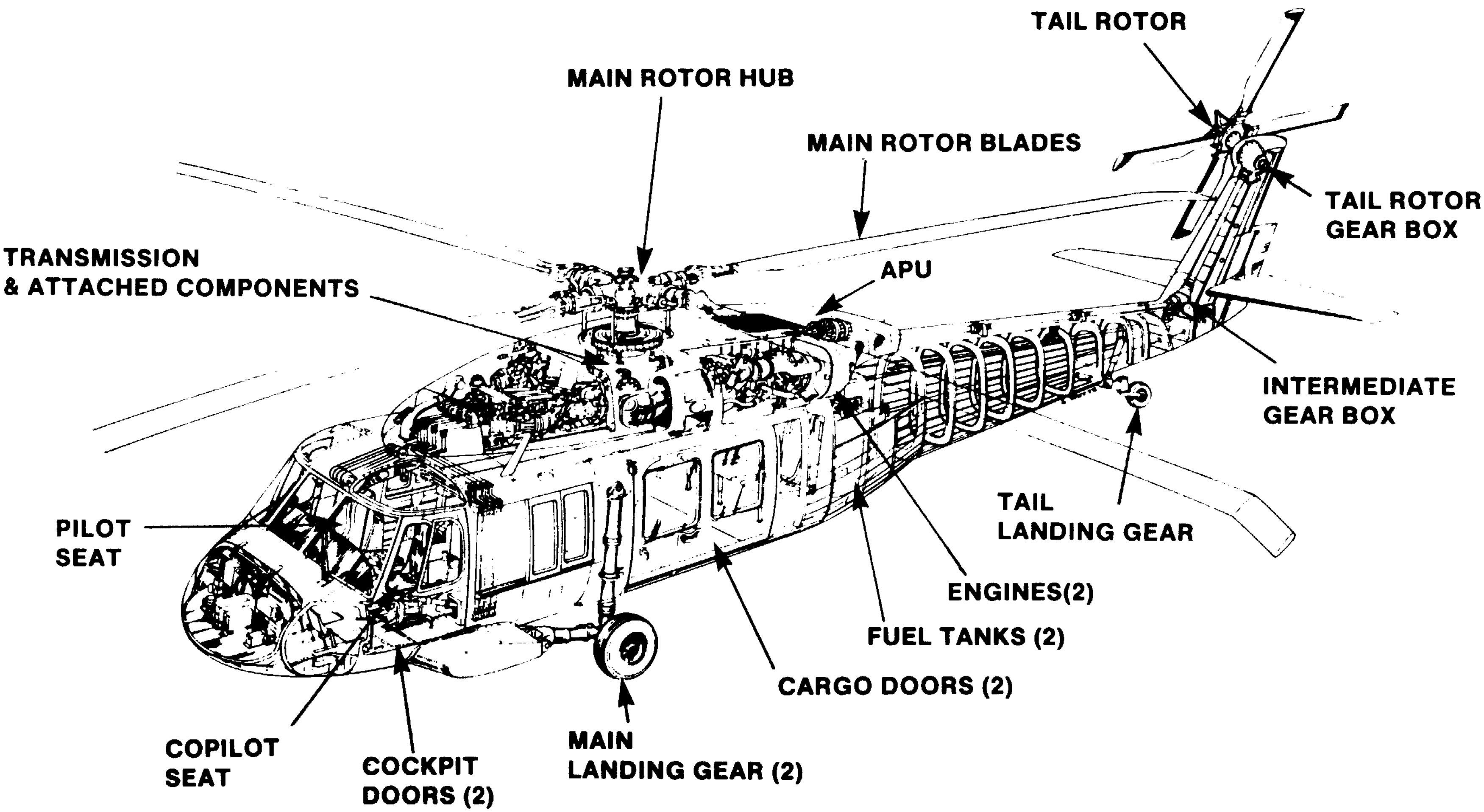
MASS MODELING
"SPECIAL-REGION" MASS COMPONENTS

The accompanying figure gives the locations of the mass components that were singled out as special regions in the present BLACK HAWK FEM.

MASS MODELING

"Special-Region" Mass Components



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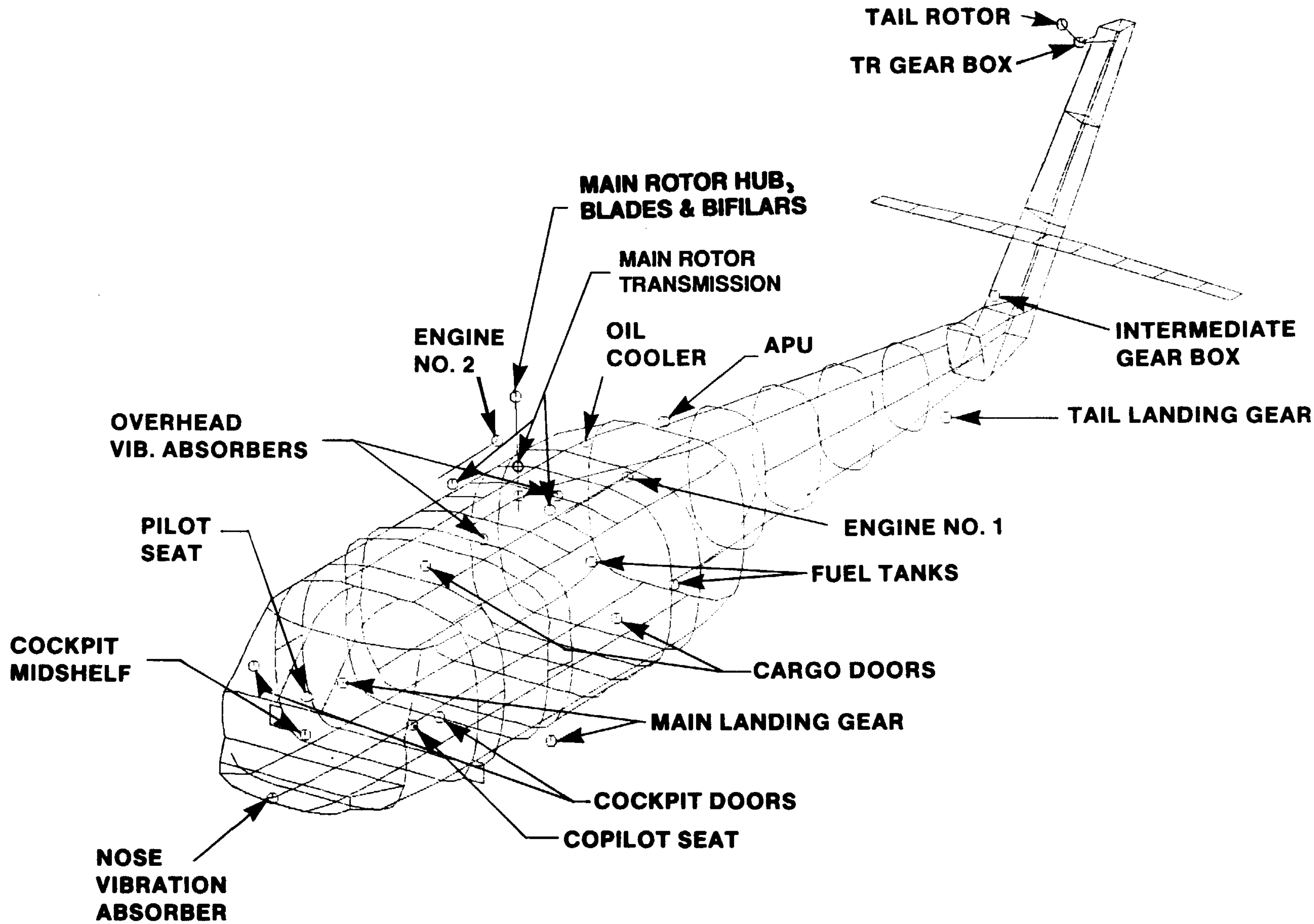
MASS MODELING
TREATMENT OF SPECIAL-REGION MASS COMPONENTS

Each special component (i.e., special region) was formed by combining its constituant parts by use of a MIL CODE Dictionary into a single mass whose weight, c.g., and moments of inertia were calculated. The center-of-gravity GRID points at which these 28 special concentrated masses are located are shown in this figure. These GRID points are connected to the adjacent structure by means of RBE3 elements.

MASS MODELING

Treatment Of Special–Region Mass Components



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SECTION 5.4
VIBRATION MODELING

VIBRATION MODELING
AIRCRAFT CONFIGURATION

An empty configuration is analyzed with no payload and no fuel, and with the vibration absorbers locked, to keep the emphasis on the modeling of the basic airframe structure.

The main rotor is treated as an actual hub weight and inertia plus 50% of the flapping weight of the blades to simulate the expected shake test configuration.

The aircraft is analyzed in the free–free condition to simulate an inflight condition.

VIBRATION MODELING

Aircraft Configuration

- Empty aircraft
- Vibration absorbers locked
- 50% of main rotor blade flapping mass
- Free-free condition

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VIBRATION MODELING
CHANGES FROM STATICS MODEL TO VIBRATION MODEL

The figure indicates the changes made from the static FEM to the vibration FEM.

Care was taken in the formulation of the static FEM so that the changes required to convert it to a vibration FEM would be minimal. As a result, the only structural difference between the two models lies in the treatment of the skin. The skins of the static model (represented by QUAD4's with Young's moduli = 0) are treated as shear-only material, in keeping with the assumption of buckled skin in severe maneuvers; the skins of the vibration model (represented by QUAD4's with appropriate Young's moduli) are treated as a material which has both inplane shear and inplane axial stiffnesses, in keeping with the assumption of unbuckled (fully-effective) skin in mild maneuvers.

The vibration model is run without SUPORT cards so that the near-zero frequencies of the six rigid body modes can serve as additional modeling checks. The remaining changes involve the reduction in the number of degrees of freedom to make dynamic analyses practicable. For modal analyses, the Generalized Dynamic Reduction method was used to effect this reduction. This reduced the number of d.o.f. from 14,981 (f-set) to 219 (a-set). Included in these 219 reduced d.o.f. were 18 physical d.o.f., associated with the main rotor hub and the engines. The remainder are the approximate mode shapes of the GDR method.

For the forced vibration analyses, the first 40 normal modes of the airframe were used as d.o.f.

VIBRATION MODELING

Changes From Statics Model To Vibration Model

- Skin changed from being effective only in shear (assumed buckled) to being fully effective in shear and axial directions (assumed unbuckled)
- SUPORT card removed
- Generalized dynamic reduction used to reduce the number of degrees of freedom for modal analyses
- Normal modes used as d.o.f. for forced vibration analyses

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SECTION 5.5
DEMONSTRATION CASES

DEMONSTRATION REQUIREMENT

The demonstration requirement for the NASTRAN model for the UH-60A is to show that the model generates reasonable (error free) results for computation of (1) static internal member loads, (2) forced response to oscillatory excitation forces at the blade passage frequency applied at the main rotor hub, and (3) natural frequencies and mode shapes.

To meet the demonstration requirement, NASTRAN runs were performed for the following:

1) Rigid Body Checks
2) Static Analysis for Internal Member Loads
3) Normal Modes Analysis
4) Forced Vibration Analysis

All demonstration cases were performed using /NASTRAN Version 64, which has been checked out and released for production usage at Sikorsky Aircraft. The rigid body check and static analysis were performed using DMAP Program SF24. This program is an in-house modification of Rigid Format 24, Static Analysis with Inertia Relief, which is standard in MSC/NASTRAN.

All runs were performed using Sikorsky Aircraft computer facilities.

DEMONSTRATION REQUIREMENT

Documentation requirement

- Model of UH–60A generates reasonable (error free) results for:
  - Static internal loads
  - Steady state forced response
  - Natural frequencies and mode shapes

Demonstration cases to meet requirement

- Rigid body checks
- Static analysis for internal member loads
- Normal modes analysis
- Forced vibration analysis

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DEMONSTRATION CASES
RIGID BODY CHECK

The procedures for performing a rigid body check are described on Page 168. The purpose of this check is to verify that the model is capable of describing rigid body motions without internal stress. Inability of the model to satisfy these criteria indicates that at certain points the stiffness of the model is inadequate (mechanisms) or the model is over–constrained i.e. the specification of single and/or multipoint constraints is improper.

In general for a three–dimensional structure there are six possible rigid body motions. For an airframe, these rigid body motions are customarily taken to be the three translation and three rotation vectors parallel to the axes of the airframe coordinate system.

In a rigid body check, six subcases are defined in NASTRAN, and in each an enforced displacement, which corresponds to one of the rigid body motions of the structure, is imposed at a single grid point. For each subcase all grid points in the model should be displaced in a manner consistent with the enforced displacement. For example, the first table in the accompanying figure shows a portion of the displacement vector for the case where a unit displacement was imposed in the TI (airframe x–axis) direction. All grid points in the model should have a displacement vector of value unity in this direction and a value of zero for all other components. The displacement vector table verifies that mechanisms do not exist in the model.

In order for the body to be capable of describing a rigid body motion the constraint forces imposed on the model must be small. To check that the forces of single point constraint are small, the standard NASTRAN output table (see second table below) is printed. To verify that the multipoint constraint equations have been properly defined, DMAP program SF24 calculates and prints the forces of multipoint constraint (see the MPCFORCE table below). If these constraints have been properly defined, these forces must be small.

DEMONSTRATION CASES

Rigid Body Check

D I S P L A C E M E N T   V E C T O R

POINT ID.	TYPE	T1	T2	T3	R1	R2	R3
5929	G	9.999999E-01	-2.832890E-14	-1.475437E-14	8.161501E-16	-7.598325E-12	4.951928E-12
5930	G	9.999999E-01	-3.620802E-14	-1.010548E-14	9.486837E-16	-8.765876E-12	8.624254E-12
5933	G	9.999999E-01	-4.319635E-14	-3.581553E-15	9.829919E-16	-9.637832E-12	1.437193E-11
5936	G	9.999999E-01	-5.100868E-14	1.261681E-14	3.914139E-16	-8.704704E-12	2.624545E-11
5937	G	9.999999E-01	-5.242681E-14	2.870447E-14	2.190630E-16	-5.427603E-12	3.598002E-11
5938	G	9.999999E-01	-5.215967E-14	4.585395E-14	4.655022E-16	-6.610962E-13	4.117022E-11
5939	G	9.999999E-01	-5.289806E-14	6.612159E-14	8.437261E-16	4.831247E-12	3.689508E-11
5941	G	9.999999E-01	-5.437231E-14	8.547416E-14	9.419548E-16	8.367071E-12	2.663998E-11
5943	G	9.999999E-01	-5.286136E-14	1.075997E-13	5.802650E-16	9.225426E-12	1.398007E-11

F O R C E S   O F   S I N G L E - P O I N T   C O N S T R A I N T

POINT ID.	TYPE	T1	T2	T3	R1	R2	R3
7636	G	0.0	0.0	0.0	4.105044E-15	0.0	0.0
7637	G	0.0	0.0	0.0	8.562595E-15	0.0	0.0
7638	G	0.0	0.0	0.0	-2.914335E-15	0.0	0.0
7649	G	0.0	0.0	0.0	1.865177E-17	0.0	0.0
7650	G	0.0	0.0	0.0	5.858770E-16	0.0	0.0
7651	G	0.0	0.0	0.0	3.508936E-16	0.0	0.0
7652	G	0.0	0.0	0.0	6.429716E-17	0.0	0.0
7655	G	0.0	0.0	0.0	1.162759E-15	0.0	0.0
7656	G	0.0	0.0	0.0	1.498336E-15	0.0	0.0

MPCFORCE

COLUMN 1 (5801-T1).

POINT	VALUE	POINT	VALUE	POINT	VALUE	POINT	VALUE	POINT	VALUE
5801 T1	3.98013E-08	5801 T2	4.41162E-10	5801 T3	-7.22684E-09	5801 R3	1.27329E-11	5802 T1	3.05736E-08
5802 T2	-6.31189E-10	5802 T3	-5.92991E-09	5849 T1	4.49945E-08	5849 T2	7.18501E-10	5849 T3	-8.60291E-09
5803 T1	3.12284E-08	5803 T2	-1.85173E-09	5803 T3	-6.74390E-09	5847 T1	4.04834E-08	5847 T2	3.75258E-09
5847 T3	-9.50268E-09	5804 T1	2.48110E-08	5804 T2	-3.16504E-09	5804 T3	-5.95446E-09	5845 T1	3.90282E-08
5845 T2	6.34282E-09	5845 T3	-7.28141E-09	5805 T1	3.76458E-08	5805 T2	-5.83532E-09	5805 T3	-6.12908E-09
5843 T1	4.33793E-08	5843 T2	4.49836E-09	5843 T3	-6.84122E-09	5843 R3	3.97904E-13	5807 T1	5.00731E-08
5807 T2	-5.41058E-09	5807 T3	-7.36054E-09	5807 R3	-3.97904E-13	5841 T1	4.34811E-08	5841 T2	3.91174E-09

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DEMONSTRATION CASES
STATIC INTERNAL LOADS
DISPLACEMENT AND ELEMENT FORCE OUTPUT

Typical NASTRAN output for the displacements at the grid points and the element forces for BAR elements for the load condition defined on Page 170 is presented in the accompanying figure.

DEMONSTRATION CASES

Static Internal Loads

Displacement And Element Force Output

D I S P L A C E M E N T   V E C T O R

POINT ID.	TYPE	T1	T2	T3	R1	R2	R3
2301	G	-2.572538E-02	-1.778738E-01	-9.905347E-01	0.0	0.0	0.0
2302	G	-4.090049E-02	-1.792288E-01	-1.050088E+00	0.0	0.0	0.0
2303	G	-5.477222E-02	-1.803235E-01	-1.106314E+00	0.0	0.0	0.0
2304	G	-6.032224E-02	-1.886741E-01	-1.153267E+00	0.0	0.0	0.0
2305	G	-6.172993E-02	-2.022294E-01	-1.206303E+00	0.0	0.0	0.0
2306	G	-6.301910E-02	-2.140703E-01	-1.253113E+00	0.0	0.0	0.0
2307	G	-4.613068E-02	-2.471004E-01	-1.294668E+00	0.0	0.0	0.0
2308	G	-2.220366E-02	-3.032622E-01	-1.327642E+00	0.0	0.0	0.0
2309	G	1.438418E-02	-3.680521E-01	-1.347214E+00	0.0	0.0	0.0
2310	G	5.525341E-02	-4.460288E-01	-1.357503E+00	0.0	0.0	0.0
2311	G	1.008612E-01	-5.318491E-01	-1.358709E+00	0.0	0.0	0.0
2312	G	1.470605E-01	-6.195463E-01	-1.352679E+00	0.0	0.0	0.0
2313	G	1.979320E-01	-6.929960E-01	-1.344188E+00	0.0	0.0	0.0
2314	G	2.489930E-01	-7.606165E-01	-1.330518E+00	0.0	0.0	0.0
2315	G	2.797399E-01	-8.003796E-01	-1.318568E+00	0.0	0.0	0.0
2316	G	3.305581E-01	-8.548176E-01	-1.293073E+00	-9.711716E-03	-9.113092E-03	1.234060E-03
2317	G	3.804178E-01	-8.960927E-01	-1.250904E+00	0.0	0.0	0.0

F O R C E S   I N   B A R   E L E M E N T S   (C B A R)

ELEMENT	BEND-MOMENT END-A		BEND-MOMENT END-B		- SHEAR -		AXIAL	
ID.	PLANE 1	PLANE 2	PLANE 1	PLANE 2	PLANE 1	PLANE 2	FORCE	TORQUE
212330	0.0	0.0	0.0	0.0	0.0	0.0	-1.422852E+02	0.0
212331	0.0	0.0	0.0	0.0	0.0	0.0	-2.848018E+02	0.0
212333	0.0	0.0	0.0	0.0	0.0	0.0	-6.875073E+01	0.0
212334	0.0	0.0	0.0	0.0	0.0	0.0	1.211013E+02	0.0
212335	0.0	0.0	0.0	0.0	0.0	0.0	1.412240E+02	0.0
212336	0.0	0.0	0.0	0.0	0.0	0.0	2.250204E+02	0.0
212337	0.0	0.0	0.0	0.0	0.0	0.0	1.116742E+02	0.0
212338	0.0	0.0	0.0	0.0	0.0	0.0	-2.083343E+02	0.0
212343	0.0	0.0	0.0	0.0	0.0	0.0	1.149794E+03	0.0
212344	0.0	0.0	0.0	0.0	0.0	0.0	2.886039E+00	0.0
212345	0.0	0.0	0.0	0.0	0.0	0.0	-2.846416E+00	0.0
212346	0.0	0.0	0.0	0.0	0.0	0.0	-6.157454E+01	0.0
212347	0.0	0.0	0.0	0.0	0.0	0.0	-1.371878E+02	0.0
212348	0.0	0.0	0.0	0.0	0.0	0.0	2.494638E+01	0.0
212349	0.0	0.0	0.0	0.0	0.0	0.0	2.116325E+02	0.0

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DEMONSTRATION CASES
STATIC INTERNAL LOADS
EQUILIBRIUM CHECKS

DMAP Program SF24 has several built-in checks to assess the quality of the solution for static internal loads. Of particular interest are the checks which assess the ability of the model to satisfy equilibrium. The accompanying figures indicates three of the equilibrium checks which are performed. These checks, which are performed by summing forces and moments about the C.G. of the aircraft, include:

1. PGSUM–Resultant of all flight loads

2. FIGSUM–Resultant of the inertia loads

3. FTGSUM–Resultant of both the flight and inertia loads.

Since for equilibrium the resultants of the inertia loads must balance those for the flight loads, the resultants of FTGSUM must be zero.

DEMONSTRATION CASES

Static Internal Loads

Equilibrium Checks

PGSUM RESULTANT

	T1	T2	T3	R1	R2	R3
1	3.8868711E+03	-3.7147466E+03	2.9712344E+04	4.5070081E+05	1.1712630E+06	-5.5137087E+05

FIGSUM RESULTANT

	T1	T2	T3	R1	R2	R3
1	3.8868591E+03	-3.7147461E+03	2.9712344E+04	4.5070781E+05	1.1717690E+06	-5.5137062E+05

FT6SUM RESULTANT

	T1	T2	T3	R1	R2	R3
1	1.2034379E-02	-2.6780367E-04	3.4745894E-03	-7.1129713E+00	-5.0556299E+02	-2.0997006E-01

UNITED TECHNOLOGIES SIKORSKY AIRCRAFT

DEMONSTRATION CASES
MODAL ANALYSIS – NATURAL FREQUENCIES

Airframe natural frequencies and modes were calculated using the Givens method of eigenvalue extraction in MSC/NASTRAN, Rigid Format 3. NASTRAN frequency tabulation and modal vector printout were obtained. Mode shape plots were obtained using the NASTRAN automated plotting capability.

Calculated natural frequencies for the first several modes are presented in this figure along with an approximate description of each mode shape.

DEMONSTRATION CASES

Modal Analysis – Natural Frequencies

MODE NO.	FREQUENCY (Hz)	DESCRIPTION
1	5.31	1st fuselage lateral bending
2	6.26	1st fuselage vertical bending
3	9.24	Stabilator roll/Yaw
4	9.91	Nose vertical/XSSN pitch
5	11.07	Stabilator Yaw/roll
6	11.80	2nd fuselage vertical bending
7	12.23	XSSN roll
8	13.14	2nd fuselage lateral bending
9	14.78	Cockpit cabin roll
10	15.56	Nose lateral
11	15.87	XSSN vertical
12	16.59	3rd fuselage vertical bending/XSSN pitch
13	19.24	Cockpit/cabin torsion
14	19.76	XSSN vertical/floor vertical
15	20.41	Cockpit torsion
16	21.25	Antisymmetric engine pitch
17	22.53	Tail rotor pylon torsion

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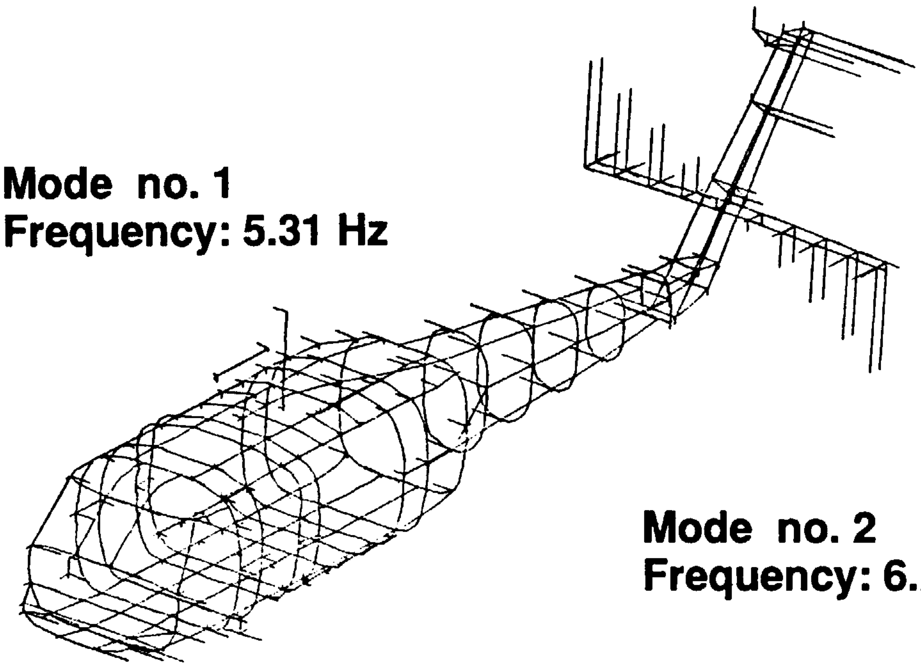
DEMONSTRATION CASES
MODAL ANALYSIS - MODE SHAPES

The mode shapes corresponding to modes 1, 2, 6 and 7 of the previously identified natural frequencies are shown in the following figures.

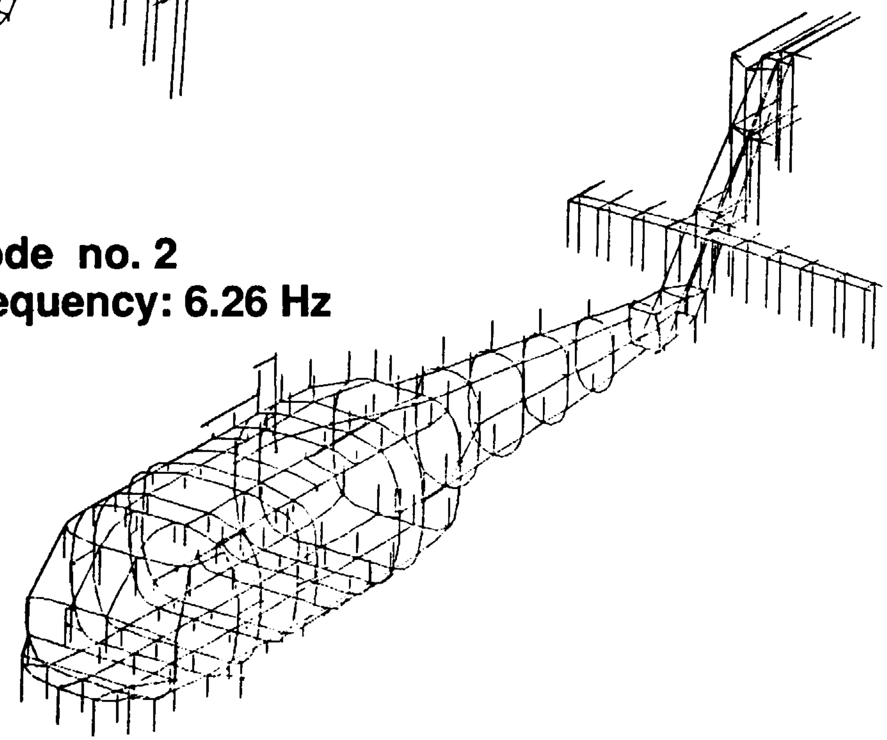
DEMONSTRATION CASES

Modal Analysis – Mode Shapes

Mode no. 1
Frequency: 5.31 Hz



Mode no. 2
Frequency: 6.26 Hz



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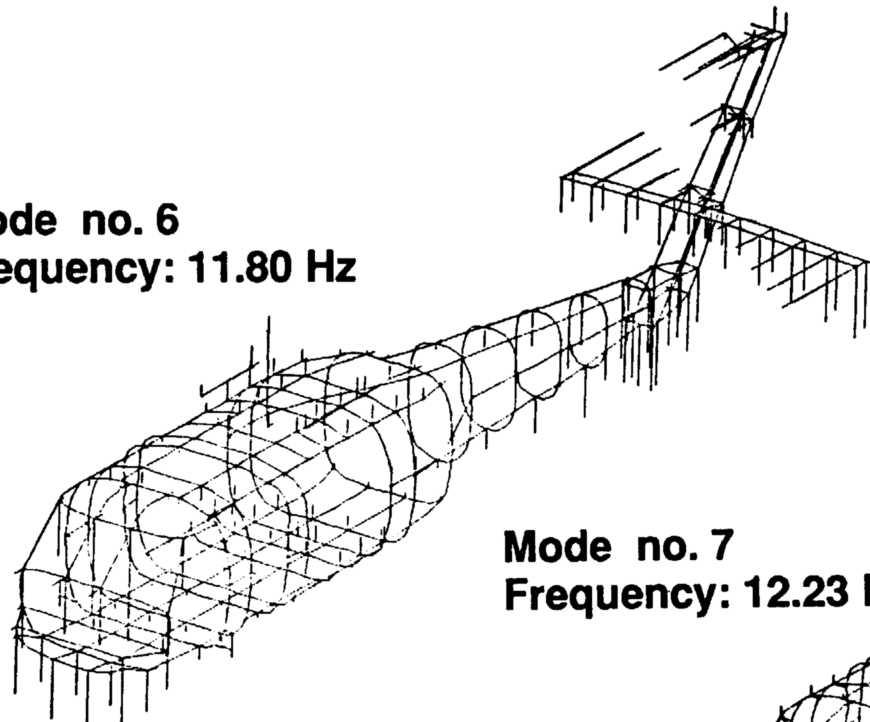
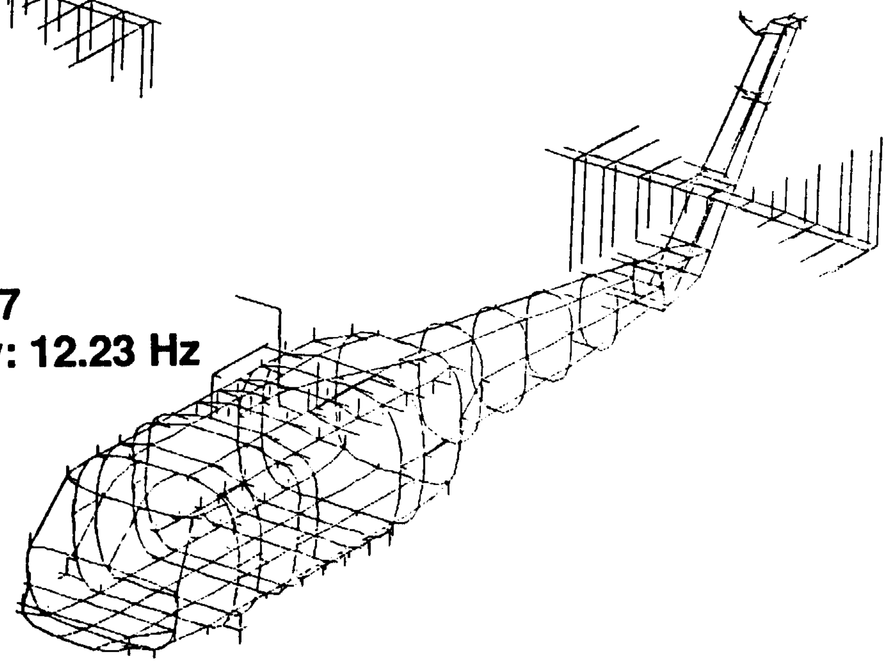
DEMONSTRATION CASES

Modal Analysis – Mode Shapes 6 & 7

Mode no. 6
Frequency: 11.80 Hz



Mode no. 7
Frequency: 12.23 Hz



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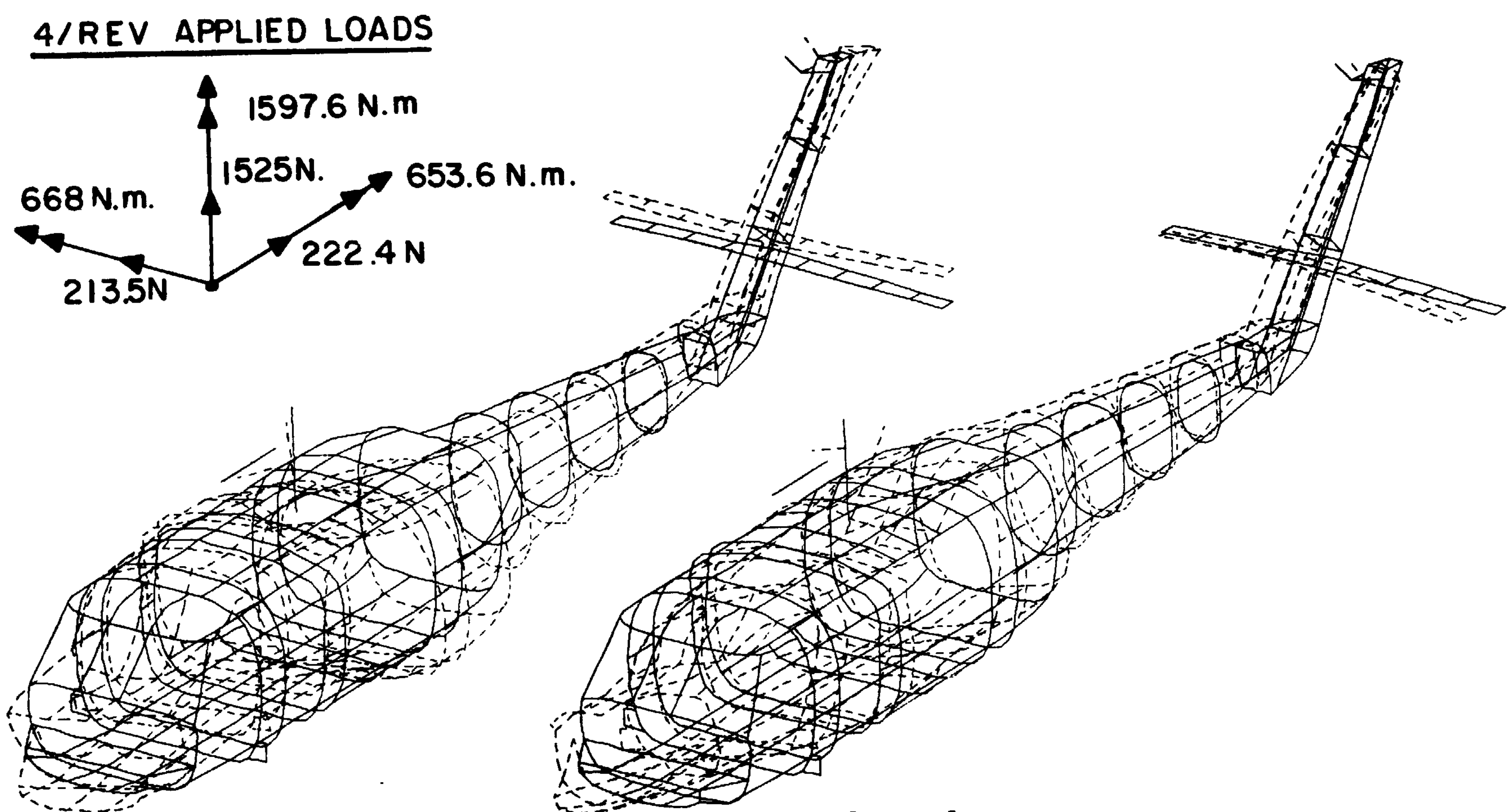
DEMONSTRATION CASES
FORCED VIBRATION - RESPONSE SHAPE

Airframe forced vibration was calculated using NASTRAN Rigid Format 30, which uses the natural modes as d.o.f. Typical 4/rev (17.2 Hz) oscillatory rotor loads were applied at the main rotor hub. The applied loads (for a 140 kt level flight) and the resulting response (real and imaginary) are shown in this figure.

DEMONSTRATION CASES

Forced Vibration – Response Shape



Real

Imaginary

DEMONSTRATION CASES
FORCED VIBRATION – ACCELERATION VECTOR

An excerpt from the tabulated forced acceleration vector at 4/rev, from which the preceding forced response shape is constructed, is presented in the following figure.

DEMONSTRATION CASES

Forced Vibration – Acceleration Vector

FEM-03 FEM -BLACK HAWK MODEL APPLIED 4/MR LOADS AT MRH GRID 9800
FREQUENCY RESP. OF RUN FEM-02(BASELINE RUN)

120 KT LEVEL FLIGHT 4/MR (ASH LOADS)AT MRH
FREQUENCY = 1.719998E+01

C O M P L E X   A C C E L E R A T I O N   V E C T O R
(MAGNITUDE/PHASE)

POINT ID.	TYPE	T1	T2	T3	R1	R2	R3
554	G	4.953760E-02 232.0024	1.316159E-01 51.2216	1.978562E-01 175.0690	0.0 0.0	0.0 0.0	0.0 0.0
2126	G	6.161503E-02 333.7017	2.897439E-02 196.4101	1.509315E-01 9.3798	0.0 0.0	0.0 0.0	0.0 0.0
2926	G	4.966645E-02 328.0249	8.697772E-02 219.6678	1.731211E-01 10.2559	0.0 0.0	0.0 0.0	0.0 0.0
3726	G	4.876534E-02 329.5083	1.299832E-01 225.6479	1.528663E-01 159.2352	0.0 0.0	0.0 0.0	0.0 0.0
6226	G	8.448583E-02 343.8279	9.709769E-02 241.2641	1.806052E-01 163.2495	2.322861E-03 223.8187	1.520385E-03 176.7783	7.838681E-04 38.3687
6526	G	9.555799E-02 345.3047	5.644028E-02 260.4563	1.091038E-01 154.8921	2.362965E-03 225.7281	1.952479E-03 175.5566	9.219470E-04 44.5211
9800	G	3.257044E-01 168.3383	2.060887E-01 218.5233	2.387964E-02 283.6267	3.155726E-03 46.1778	7.939532E-03 183.0458	1.997298E-02 66.6088
60008	G	2.895158E-01 40.5138	1.892679E-01 13.3039	3.113636E-01 165.4943	1.209087E-02 164.1467	8.530166E-03 30.4310	5.534496E-03 27.2128
60009	G	1.623141E-01 296.1843	1.000623E-01 84.6269	2.425969E-01 155.2577	8.214522E-03 302.6558	5.590837E-03 211.5032	3.658525E-03 58.8005
60014	G	3.533564E-02 332.6028	9.856951E-02 41.4941	1.265298E-01 4.0620	1.459489E-04 230.4392	2.011820E-03 166.5166	9.167276E-04 113.9630
60015	G	1.953754E-01 7.4367	5.361608E-02 234.8211	1.020995E-01 355.5312	5.311958E-03 100.4776	3.903622E-03 16.5544	7.501535E-03 145.4389
60016	G	2.657722E-01 358.5049	7.223076E-02 244.8691	9.801525E-02 22.3249	5.311958E-03 100.4776	3.903622E-03 16.5544	7.501535E-03 145.4389
60022	G	7.160962E-02 199.5191	9.812832E-02 52.1802	6.404275E-02 265.8337	4.066169E-03 225.3134	6.230921E-03 188.9415	1.000057E-03 230.2624
60023	G	1.057389E-01 210.5982	1.243246E-01 41.8553	1.905459E-01 25.8436	5.510774E-03 214.6610	5.531028E-03 182.9041	1.025340E-03 231.3567

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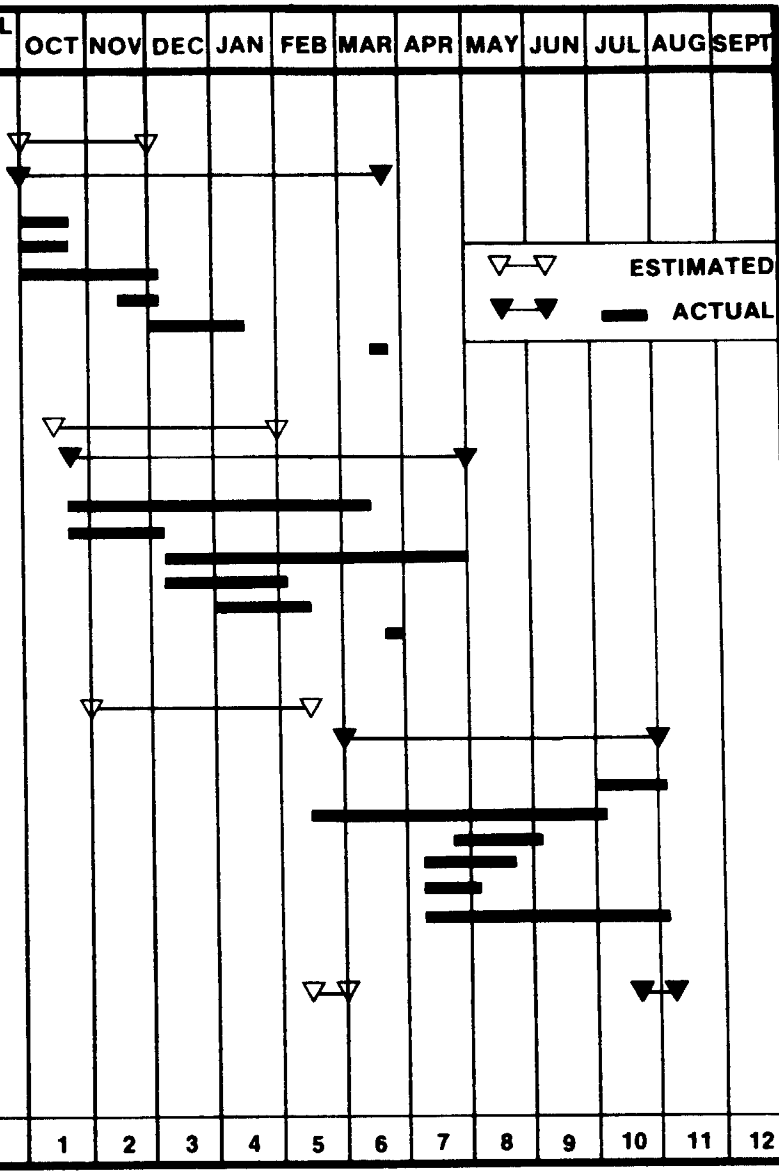
SECTION 5.6
COMPARISON OF PROJECTED AND ACTUAL SCHEDULES AND MAN-HOURS

STATIC MODELING SCHEDULE

This figure summarizes the static modeling effort for the BLACK HAWK. A comparison of the estimated manhours and planned schedule, and the actual manhours and schedule are presented. Elapsed time as well as total manhours exceeded the estimates, the latter exceeding estimates by about 25%.

STATIC MODELING SCHEDULE

ACTIVITY	ELEM	EST M/H	ACTUAL M/H
1. Define geometry of GRID points		320	546
Cockpit	1132		116
Cabin	2282		186
Transition Section	2521		164
Tailcone	1294		34
Stabilator/Tail rotor pylon	742		30
Special components	785		16
2. Number GRID points & elements & connectivity checks		800	983
Cockpit	1132		254
Cabin	2282		390
Transition Section	2521		218
Tailcone	1294		68
Stabilator/Tail rotor pylon	742		32
Special components	785		21
3. Calculate element section properties		1700	2031
Cockpit	1132		312
Cabin	2282		1118
Transition Section	2521		343
Tailcone	1294		108
Stabilator/Tail rotor pylon	742		110
Special components	785		40
4. Rigid body checks and static Demonstration case		100	78
TOTAL M/H		2920	3638
MONTH			



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MASS MODELING SCHEDULE

This figure summarizes the mass modeling effort for the BLACK HAWK. A comparison of the estimated and actual schedule and manhours is presented. The delay in the schedule was due to slippage in the static modeling schedule upon which it depended. The actual manhours exceeded the estimated by about 10%.

MASS MODELING SCHEDULE

ACTIVITY	ELEM	EST M/H	ACTUAL M/H	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT
1. Define geometry of distributed-mass regions and define special-mass regions (Input for Mass Properties/NASTRAN Interface Program (E94AB))		40	44												
2. Run program E94AB -Output CONM2 cards & corresponding GRID cards (Mass, c.g., and inertias of distributed mass in each region)		360	408												
3. Generate RBE3 cards to connect above mass GRID points to structural GRID points		40	30												
TOTAL M/H		440	482												
MONTH				1	2	3	4	5	6	7	8	9	10	11	12

▽—▽ ESTIMATED

▼—▼ ACTUAL

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VIBRATION MODELING SCHEDULE

The figure summarizes the effort required to generate the BLACK HAWK FEM vibrations model and satisfy the demonstration requirements. A total of 510 manhours was required compared to an estimated 800.

VIBRATION MODELING SCHEDULE

ACTIVITY	EST M/H	ACTUAL M/H	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT
1. Static FEM coordination	280	310												
2. Modification of FEM for vibration	160	10												
3. Prepare data for modal analysis A. Transfer FEM to dynamics TSO file B. JCL C. Case control deck D. Plot set, including PLOTEL cards E. Bulk data cards, freq.	120	62												
4. Computer solution, modal analysis demonstration case A. Run case w/o support card B. Rigid-body freq. check C. SPC force check D. Freq. & mode shapes check (no non-physical low-freq. local modes) E. Reruns correcting errors	160	106												
5. Computer solution, forced reponse demonstration case A. Prepare bulk data force input B. Prepare case control C. Run case & check results D. Reruns correcting errors	80	22												
TOTAL M/H	800	510												
MONTH			1	2	3	4	5	6	7	8	9	10	11	12

ESTIMATED

ACTUAL

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SECTION 6
CONCLUDING REMARKS

SUMMARY OF PROGRAM

This report summarizes the development, documentation, and initial validation of a finite element model of the UH–60A BLACK HAWK helicopter. A plan was defined for formulating a NASTRAN model of the UH–60A helicopter prior to the actual development of the model. Included in this planning effort was the preparation of a complete description of the UH–60A airframe structure and its power and drive train systems. Guidelines were established for the actual coding of the model. These guidelines included the numbering schemes used for identifying the grid points and elements, and the techniques used to represent the major structural components of the airframe, as well as the components of the power and drive train systems. Procedures were also defined for development of the mass model.

The NASTRAN finite element analysis model of the UH–60A helicopter that resulted from this effort was developed according to the above plan. Deviations from the plan which were deemed necessary to improve the model were fully documented. A complete description of NASTRAN model was also provided, including descriptions of the statics, mass, and vibration model.

Demonstrated cases were also performed to verify that the model produced reasonable and error free results. The cases that were performed using NASTRAN included a rigid body check, as well as analyses for static internal loads, natural frequencies and mode shapes, and steady state forced response.

SUMMARY OF PROGRAM

- Defined a plan for formulating a NASTRAN model of the UH–60A
  - Provided a complete description of the UH–60A
  - Defined guidelines for formulating the model
- Built the UH–60A NASTRAN model according to the plan
  - Documented deviations from the plan
- Described the UH–60A NASTRAN model
  - Statics model
  - Mass model
  - Vibration model
- Performed demonstration cases to validate the model
  - Rigid body checks
  - Static internal loads
  - Natural frequencies and mode shapes
  - Steady state forced response

UNITED TECHNOLOGIES SIKORSKY AIRCRAFT

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LANGLEY TECHNICAL MONITOR: RAYMOND G. KVATERNIK
FINAL REPORT (FOR TASK NO. 2 OF THE CONTRACT)

16. Abstract

Under a rotorcraft structural dynamics program sponsored by the NASA Langley Research Center, Sikorsky Aircraft, together with the other major helicopter airframe manufacturers is engaged in a study to improve the use of finite element analysis to predict the dynamic behavior of helicopter airframes. This program, which has been designated DAMVIBS (Design Analysis Methods for VIBrationS), includes activities in the areas of : planning, creating, and documenting finite element models of helicopter airframes; the performance of ground vibration tests; and the correlation of test and analysis.

This report summarizes the work performed at Sikorsky Aircraft for planning, creating and documenting a finite element model of the UH-60A BLACK HAWK helicopter airframe. A complete description of the components of the helicopter which are to be represented in the model is presented in the report and includes: the structural arrangement, the identification of primary and secondary structure, the components of the drive and power trains, and the attachment of large weight items to the structure. Also presented are the techniques which were used to formulate the structural finite element model for static analysis, for forming the mass and vibration models for dynamic analysis, and the procedures which were used to check out and verify the integrity of the model. Initial predictions for the vibration modes for the helicopter are included in the report.

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